الهيئــة العـامــة للطيـــران المـدنـــي
GENERAL CIVIL AVIATION AUTHORITY

United Arab Emirates

Air Accident Investigation Sector

Serious Incident

- Final Report -

AAIS Case N°: AIFN/0005/2013

Unreliable Airspeed Indication

Operator: ETIHAD AIRWAYS
Type: Airbus A340-600
Registration: A6-EHF
Location: International Water after Passing Colombo FIR, Entering Melbourne FIR
Date of Occurrence: 3 February 2013

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GENERAL CIVIL AVIATION AUTHORITY

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Incident Brief

GCAA AAI Report No.:	AIFN/0005/2013
Operator:	Etihad Airways
Aircraft Type and Registration:	Airbus A340-600, A6-EHF
MSN	837
No. and Type of Engines:	Four Rolls-Royce (RR) TRENT 500, Turbofan Engines
Date and Time (UTC):	3 February 2013, 0050 UTC
Location:	Between Waypoints ELATI and PIPOV, after Passing Colombo FIR and Entering the Melbourne FIR
Type of Flight:	Passenger Transport
Persons Onboard:	295 persons (4 flight crewmembers, 13 cabin crew and 278 passengers)
Injuries:	None

Investigation Objective

This Investigation considers aspects related to unreliable airspeed indication and high N1 vibration of the No.2 engine, that affected the Airbus A340-600 Aircraft, registration A6-EHF, and the consequent diversion of the aircraft.

The Investigation is performed pursuant to the UAE Federal Act No 20 of 1991, promulgating the Civil Aviation Law, Chapter VII, Aircraft Accidents, Article 48. It is in compliance with the UAE Civil Aviation Regulations, Part VI, Chapter 3, in conformity with *Annex 13 to the Convention on International Civil Aviation* and in adherence to the *Air Accidents and Incidents Investigation Manual*.

The sole objective of this Investigation is to prevent aircraft accidents and incidents. It is not the purpose of this activity to apportion blame or liability.

Investigation Process

The occurrence involved an Airbus A340-600 Passenger Transport Aircraft, registration A6-EHF, and was notified to the General Civil Aviation Authority (GCAA) by phone call to the Duty Investigator (DI) Hotline Number +971 50 641 4667.

Following the Initial/On-Site Investigation phase, the occurrence was classified as a 'Serious Incident'.

In accordance with the Standard Practice of *Annex 13 to the Convention on International Civil Aviation*, an Investigation Team was formed by the United Arab Emirates (UAE), GCAA, being the State of Registry. The International Civil Aviation Organization (ICAO) and the State of Design and Manufacture (France) Bureau d'Enquêtes et d'Analyses (BEA) were notified in line with the ICAO *Annex 13* obligations.

The BEA and the United Kingdom Air Accidents Investigation Branch (AAIB), being the State of engine manufacturer, assigned Accredited Representatives to the Investigation.

The scope of this Investigation is limited to the events leading up to the occurrence; no in-depth analyses of non-contributing factors were undertaken.

Notes:

1 Whenever the following words are mentioned in this Report with the first letter Capitalized, it shall mean:

- (Aircraft) - the aircraft involved in this Serious Incident.
- (Investigation) - the investigation into this Serious Incident.
- (Incident) - this investigated Serious Incident.
- (Report) - this Serious Incident Report.

2 Unless otherwise mentioned, all times in this Report are Coordinated Universal Time (UTC), (UAE Local Time minus 4).

3 Photos used in the text of this Report are taken from different sources and are adjusted from the original for the sole purpose to improve clarity of the Report. Modifications to images used in this Report are limited to cropping, magnification, file compression, or enhancement of color, brightness, contrast or insertion of text boxes, arrows or lines.

Abbreviations and Definitions

AAIS	Air Accident Investigation Sector of the United Arab Emirates
ACMS	Aircraft Condition Monitoring System
ADIRU	Air Data Inertial Reference Unit
AD	Airworthiness Directive
ADM	Air Data Module
ADR	Air Data Reference
ADV	Advisory
ALTN	Alternate Law
AOA	Angle of Attack
AP	Autopilot
ATA	Air Transport Association Chapter
ATC	Air Traffic Control
A/THR	Autothrust
ATPL	Air Transport Pilot License
AUTO	Automatic
BEA	Bureau d'Enquêtes et d'Analyses
CAR	Civil Aviation Regulation of the United Arab Emirates
CAS	Computed Air Speed
CAPT	Captain
Cb	Cumulonimbus
CG	Center of Gravity
C of A	Certificate of Airworthiness
C of R	Certificate of Registration
CPDLC	Controller Pilot Data Link Communications
CPL	Commercial Pilot License
CVR	Cockpit Voice Recorder
DAR	Digital ACMS (Aircraft Condition Monitoring System) Recorder
DMC	Display Management Computer
EASA	European Aviation Safety Agency
E/WD	Engine/Warning Display
ECAM	Electronic Centralized Aircraft Monitoring
EFIS	Electronic Flight Indication System
ELP	English Language Proficiency

ENG	Engine
EPR	Engine Pressure Ratio
FCC	Flight Control Computer
FCDC	Flight Control Data Concentrator
FCPC	Flight Control Primary Computer
FCRC	Flight Crew Rest Compartment
FCSC	Flight Control Secondary Computer
FCTM	Flight Crew Training Manual
FCS	Flight Control System
FCU	Flight Control Unit
FD	Flight Director
FDR	Flight Data Recorder
FIR	Flight Information Region
FL	Flight Level
FMGEC	Flight Management Guidance and Envelope Computer
FMGES	Flight Management Guidance and Envelope System
F/O	First Officer
FWC	Flight Warning Computer
GCAA	General Civil Aviation Authority of the United Arab Emirates
HF	High Frequency
HP	High-Pressure
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IR	Inertial Reference
IRS	Inertial Reference System
ISIS	Integrated Standby Instrument System
LP	Low-Pressure
MAN	Manual
mbar	millibars
MCC	Maintenance Control Center
ND	Navigation Display
M/E	Multi Engines
MEL	Minimum Equipment List

MMO	Maximum Operating Mach
MPD	Maintenance Planning Document
MSN	Manufacturer Serial Number
No	Number
NOC	Network Operations Centre
PF	Pilot Flying
PFD	Primary Flight Display
PHC	Probe Heat Computer
PLAN	Flight Plan
P/N	Part Number
PRIM	Flight Control Primary Computer
QAR	Quick Access Recorder
QRH	Quick Reference Handbook
RR	Rolls-Royce
RVSM	Reduced Vertical Separation Minimum
RWY	Runway
SD	System Display
SDAC	System Data Acquisition Concentrator
SEC	Flight Control Secondary Computer
SFCC	Slat and Flap Control Computer
S/N	Serial Number
SPD LIM	Speed Limit
SR	Safety Recommendation
STBY	Standby
TAT	Total Air Temperature
UAE	The United Arab Emirates
ULR	Ultra Long Range
UTC	Coordinated Universal Time
VIB	Vibration
VLS	Lowest Selectable Speed
VMC	Visual Meteorological Conditions
VMO	Maximum Operating Speed
VS1G	Stall Speed at 1g Load Factor
VSW	Stall Warning Speed

Synopsis

On 2 February 2013, an Airbus A340-600 Aircraft, registration A6-EHF, operating a scheduled passenger flight to Melbourne International Airport, Australia, departed Abu Dhabi International Airport at approximately 1935 UTC. There were a total of 295 persons onboard: 4 flight crew members, 13 cabin crew and 278 passengers. . The captain was the pilot flying (PF) and the first officer was the pilot monitoring (PM).

While cruising at FL350, just leaving the Colombo FIR and entering the Melbourne FIR, the Aircraft encountered moderate to heavy turbulence, and experienced significant airspeed oscillations on both the captain's and the standby airspeed indicators. The autopilot, autothrust, and flight directors disconnected automatically. The flight control law changed from "Normal" to "Alternate" Law, leading to the loss of some flight mode and flight envelope protections. Changes from Normal to Alternate Law occurred twice; thereafter the Aircraft remained in Alternate Law until the end of the flight. The autothrust system and the flight directors were successfully re-engaged, however, neither autopilot (autopilots 1 or 2) could be re-engaged, thus the Aircraft was flown manually until landing. In addition to the system anomalies, the Aircraft experienced high N_1 vibration on the No. 2 engine.

As the Aircraft had lost capability to maintain Reduced Vertical Separation Minima (RVSM) the flight crew decided to divert to Singapore, Changi International Airport. The diversion required the flight crew to dump fuel in order to land the Aircraft below its maximum landing weight.

The landing was uneventful and none of persons onboard were injured.

The GCAA preserved the cockpit voice recorder and the flight data recorder and they were brought to the Flight Recorder Laboratory at the GCAA Headquarters in Abu Dhabi for playback and analysis.

The Investigation, conducted by the Air Accident Investigation Sector (AAIS) of the UAE General Civil Aviation Authority (GCAA), determined that the cause of this Unreliable Airspeed Indication Serious Incident was the intermittent obstruction of the Aircraft left side pitot probes due, most probably, to an accumulation of ice crystals which caused temporary blockages of the pitot probe.

The Investigation determined that the cause of the No. 2 engine N1 vibration was ingress of water through a gap created after the Omega Seal disbanding. The water froze to ice, which entered and passed through the spinner fairing and accreted under the annulus fillers.

The Investigation identifies the following contributory causal factors to the Unreliable Airspeed Indication Serious Incident:

- An incorrect radar tilt setting was selected, such that the flight crew would not be made aware that the Aircraft would encounter an area of isolated embedded cumulonimbus clouds;
- The ambient temperature and the Aircraft altitude were beyond the certified icing envelope of the JAR specification and the manufacturer requirements.

Four safety recommendations are included in this report. They are addressed to the Operator, EASA and the GCAA.

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CONTENTS

1. Factual Information

1.1 History of the Flight

On 2 February 2013, at approximately 1935 Coordinated Universal Time (UTC), an Airbus A340-600 Aircraft, registration mark A6-EHF, departed Abu Dhabi, United Arab Emirates (UAE) operating a scheduled passenger flight, number ETD460, to Melbourne, Australia. There were a total of 295 persons onboard: 4 flight crew members, 13 cabin crew members and 278 passengers. The captain was the pilot flying (PF).

On 3 February 2013, at approximately 0049 UTC, the Aircraft was cruising at flight level (FL) 350[1] on airway N640 between waypoints ELATI and PIPOV, just entering the Melbourne FIR[2] from the Colombo FIR, with Autopilot (AP) 1 and Autothrust (A/THR) engaged.

The Aircraft was flying in light turbulence in Instrument Meteorological Conditions (IMC) within Cirrocumulus cloud, which was approximately 5,000 to 7,000 feet (ft) in thickness. The weather radar was showing almost no, or very few green returns with the setting on Gain: Auto, and manual radar tilt set to -0.8. The Aircraft was not equipped with an automatic radar tilting system.

The turbulence started to increase slightly and the radar returns became stronger from mainly black to 80% green, then from green to 80% yellow. Suddenly, the displayed radar returns depicted 2-3 millimeters of solid red around the aircraft symbol.

The airspeed indication on the captain's Primary Flight Display (PFD1)[3] started to oscillate slightly. At 00:50:04, the airspeed indication dropped from 283 knots (kts) to 77 kts in two seconds and then increased to approximately 270 kts. During the same period of time, the airspeed indications on PFD2 and on the standby instrument were stable.

Starting at 00:50:10, the captain's airspeed indication decreased from 270 kts to 76 kts, the first officer's (F/O) airspeed indication remained constant while the standby indication decreased from 280 kts to 142 kts.

At 00:50:12, AP1, A/THR and both Flight Directors (FD) automatically disengaged. On the Electronic Centralized Aircraft Monitoring (ECAM)[4] page, the flight crew noticed the following displayed messages: AUTO FLT AP OFF in red[5], and A/THR OFF in amber[6].

At 00:50:15, the Aircraft flight control law changed from Normal to Alternate Law. All anti-icing and probes/window heaters were turned ON by the flight crew.

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1 FL350 = 35,000 feet above mean sea level when the pressure at sea level is 1013.2 mbar.

2 Flight Information Region is a specified region of airspace in which a flight information service and an alerting service are provided which is the largest regular division of airspace in use in the world today.

3 PFD1 and PFD2: Left and right Primary Flight Display, respectively.

4 Electronic Centralized Aircraft Monitoring is to provide information of the status of aircraft and its systems including caution and warning messages, and Indicate required flight crew actions in most normal, abnormal and emergency situations.

5 AUTO FLT AP OFF Warning means that Autopilot system is disengaged

6 A/THR OFF Caution means that Autothrust is disengaged

At 00:50:18, the captain's airspeed indication increased from 76 to 285 kts, subsequently both FDs automatically re-engaged.

At 00:50:22, the captain's and the standby airspeed indications recovered and showed constant readings of approximately 280 kts on the captain's side, and 276 kts on the standby indicator. Subsequently, the control law returned to Normal Law.

At 00:51:02, the captain successfully re-engaged the A/THR. The Engine Pressure Ratios (EPRs) started to decrease in order to reach the pre-selected 0.75 Mach Number. During the same period of time, the Aircraft started to depart its cruise altitude.

Between 00:51:04 and 00:51:48, significant airspeed fluctuations started again on PFD1 and the standby indicator, while PFD2 was still showing steady airspeed.

At 00:51:28, the flight control law reverted to Alternate Law and the aircraft remained in Alternate Law to the end of the flight. The flight crew noticed a NAV ADR DISAGREE message in amber[7] and an ALTN LAW PROT LOST message in amber[8] on the ECAM page.

At 00:51:30, both FDs and the A/THR automatically disconnected for the second time. Two seconds later, both FDs automatically re-engaged, and after another two seconds, both FDs automatically disconnected again.

The captain stabilized the aircraft at 00:51:46, and he transferred control to the F/O, since all the F/O's instruments appeared to be functioning normally.

After 00:51:48, the captain's and the standby airspeed indications recovered and stabilized at approximately their previous values. Both FDs re-engaged automatically at 00:51:49.

The F/O descended the Aircraft to the FL350 target altitude after the inadvertent climb to 832 ft above that altitude, subsequent to the AP disengagement. The F/O also noticed that a red SPD LIM[9] warning had appeared at the bottom of the speed tape on PFD2.

At 00:51:54, the A/THR was re-engaged successfully.

The flight crew attempted to re-engage the AP several times but neither AP1 nor AP2 could be successfully re-engaged. The captain's air data was switched to Air Data Reference 3 (ADR 3)[10].

The F/O continued to fly the Aircraft manually, with A/THR engaged. As the flight crew initiated the ADR CHECK PROC[11] checklist, the three speed indications (captain, F/O and standby) returned to normal, but the speed tapes were showing the SPD LIM warning flag in red and this remained so for the remainder of the flight. Consequently,

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7 NAV ADR DISAGREE caution warning means that two ADR outputs are erroneous, but different, and the remaining ADR is correct, or if all three ADRs are erroneous, but different.

8 ALTN LAW PROT LOST caution warning means that Dual NAV ADR or NAV IRS failures will cause the loss of autopilot (AP) and autothrust (A/THR) and the flight controls law revert to Alternate Law (ALTN LAW)

9 SPD LIM red flag warning means Lowest Selectable Speed (VLS) and Stall Warning Speed (V_{SW}) are lost.

10 ADR3 is the Air Data Reference of the standby system

11 ADR CHECK PROC is a QRH procedure to identify and to isolate the affected ADRs when unreliable speed indication occurred

the ADR CHECK PROC was not performed. No other ECAM action needed to be completed. In the meantime, the captain asked the cabin manager (CM) to bring the relief captain, who was resting in flight crew rest compartment (FCRC), to the flight deck, to assist the captain flying in attempting to recover to Normal Law, and to engage one of the APs.

The flight crew attempted to communicate with Brisbane Air Traffic Control (ATC) on the High Frequency (HF) radio in order to advise of the situation but contact could not be established. Subsequently, a message was sent, via the on-board Controller Pilot Data Link Communications (CPDLC)[12], to Melbourne ATC declaring a PAN-PAN[13] due to Aircraft performance, weather and turbulence.

Together with the relief captain, who was present on the flight deck having returned from his rest, the flight crew performed a reset of all Flight Control Computers (FCCs) and Flight Management Guidance and Envelope Computers (FMGECs) by using the QRH COMPUTER RESET TABLE in an attempt to recover at least one AP. However, neither of the two APs re-engaged following the reset.

The flight crew communicated with the Operator's Maintenance Control Center (MCC)[14] Duty Manager who advised that the Aircraft had transmitted an N1 high vibration message for the No. 2 engine. The flight crew did not notice any Advisory (ADV) message, but they did confirm the high N1 vibration on the ECAM ENG (Engine) page. The high N1 vibration on the No. 2 engine started during the airspeed indication fluctuations.

The MCC also suggested that an attempt be made to reset the computers of the System Data Acquisition Concentrator (SDAC[15]) and the Flight Control Data Concentrator (FCDC[16]). After consulting the QRH COMPUTER RESET TABLE, the flight crew attempted to reset both, but with no subsequent effect.

In coordination with the MCC, the flight crew decided to divert to Singapore Changi International Airport (WSSS[17]), due to the availability of maintenance logistics in Singapore. The Operator's Network Operations Centre (NOC)[18] was informed of the decision to divert.

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12 Controller Pilot Data Link Communications (CPDLC) is a datalink communication between pilots and controllers, which is considered to be the primary means of communication over oceans and in remote areas.

13 PAN PAN (three calls) is an urgency call or message (situation not requiring immediate assistance) by the flight crew declaring the situation to the ATC.

14 MCC is the Operator's Maintenance Control Center, which supports and provides advises on any operational and technical issues during any phase of the operation of the aircraft which is reported by the flight crew.

15 SDAC recopies a certain number of parameters, performs acquisition of the data (ARINC 429, discrete, and analog data), and to redistribute them to other equipment in digital form (ARINC 429 standard).

16 FCDC makes the interface between the flight control computers (FCPCs and FCSCs) and the other systems (display system, maintenance system, and recording system), and have the function of data concentration, warning transmission, and maintenance aid for the flight control system

17 WSSS is the ICAO's 4 letter airport code for Singapore Changi International Airport

18 NOC is the Operator's Network Operations Centre (NOC) is the 24hours designated control center for Operator's global operations and is resourced to ensure the daily supervision and management of the flight operation, including aircrew.

The captain advised Melbourne ATC of the loss of Reduced Vertical Separation Minima (RVSM)[19] capability, via the CPDLC.

The flight crew stated that it took approximately 20 minutes to get a reply and clearance from Melbourne ATC, via CPDLC, to divert towards Singapore. They also tried to communicate via HF, but the signal quality was very poor.

During the diversion, the Aircraft descended to FL290 in order to vacate RVSM airspace and maintain Visual Meteorological Conditions (VMC), since the flight crew could not ascertain the serviceability status of the weather radar. Later the flight crew realized that the weather radar was working normally, as the Cumulonimbus clouds on approach to Singapore were displayed normally.

Shortly before descent from FL290, with authorization from Jakarta ATC, the flight crew started to dump approximately 9 tons of fuel in order to land at Singapore at, or below, the maximum landing weight.

At FL290, the relief F/O, who had returned to the cockpit from his rest period, took over from the duty F/O. The relief F/O continued to fly the Aircraft manually until it had descended to FL100. The captain then took over the controls and performed an uneventful Instrument Landing System (ILS) approach and landing on Runway (RWY) 02L at Singapore Changi International Airport.

1.2 Injuries to Persons

There were no injuries to persons as a result of this Incident.

Injuries	Flight Crew	Cabin Crew	Other Flight Crew Onboard	Passengers	Total Onboard	Others
Fatal	0	0	0	0	0	0
Serious	0	0	0	0	0	0
Minor	0	0	0	0	0	0
None	2	13	2	278	295	0
TOTAL	**2**	**13**	**2**	**278**	**295**	**0**

1.3 Damage to Aircraft

The Aircraft was undamaged.

1.4 Other Damage

There was no other damage to property and/or the environment.

[19] Reduced Vertical Separation Minima or Minimum (RVSM) is the reduction of the standard vertical separation required between aircraft flying between FL290(29,000 ft) and FL410 (41,000 ft) inclusive, from 2,000 feet to 1,000 feet.

1.5 Personnel Information

	Captain (operating pilot[20])	First officer (operating pilot)	Captain B (relief pilot[21])	First Officer B (relief pilot)
Date of Birth	31 January 1974	6 September 1988	2 December 1969	22 May 1981
UAE License Validity	24 March 2016	16 October 2019	13 June 2018	28 June 2019
UAE License Category and Rating	ATPL; M/E Land, A332, A343, A345, A346, ETOPS, CAT III	CPL; M/E Land, INSTRUMENT. A340	ATPL; M/E Land, A330, A340 (P2)	ATPL; M/E Land, A330(P2), A340 (P2)
Class and Date of Last Medical	Class I (One); 11 November 2012	Class I (One); 05 February 2012	Class I (One); 14 February 2012	Class I (One); 8 February 2012
Flying Experience				
Total All Types	10,636.20 Hours	520.04 Hours	9,159.04 Hours	5,759.16 Hours
Total Command on All Types	3,050.47 Hours	---	2,135.04 Hours	1,141.11 Hours
Total on Type	1,094.54 Hours	324.21 Hours	216.46 Hours	189.38 Hours
Total last 1 Year	866.57 Hours	369.35	369.35 Hours	563.22 Hours
Total last 28 Days	71.30 Hours	48.48 Hours	23.49 Hours	27.30 Hours
Total last 14 Days	28.20 Hours	41.54 Hours	23.49 Hours	19.11 Hours
Total last 7 Days	5.26 Hours	20.49 Hours	2.21 Hours	2.21 Hours
English Language Proficiency (ELP)	Level 5	Level 6	Level 5	Level 6

[20] Pilot who performs the operation of flight during the Incident

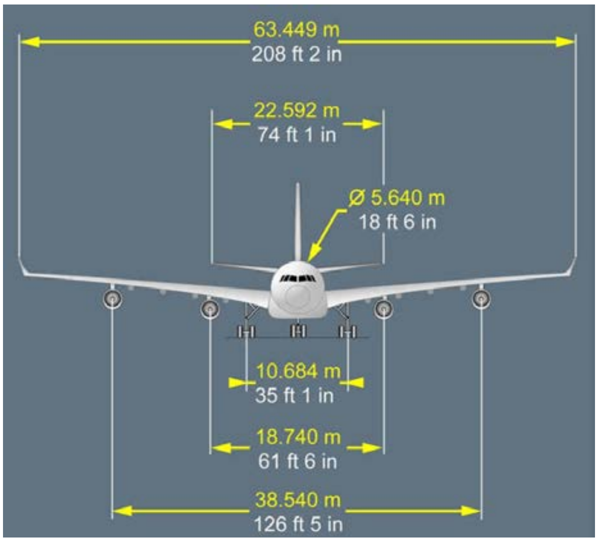
[21] Appointed as standby pilot, especially for Ultra Long Range (ULR) operation

1.6 Aircraft Information

1.6.1 General

General Aircraft information	
Make and Model:	Airbus A340-600
Manufacturer Serial Number (MSN):	837
Manufacturing Year	2007
State of Registry:	United Arab Emirates
Registration:	A6-EHF
Time Since New (TSN):	29,609 Hours
Cycles Since New (CSN):	3,405 Cycles
Certificate of Airworthiness (CoA)	
Issuing Authority:	UAE General Civil Aviation Authority
Issuance date:	28 August 2007 (first issue)
Valid until:	27 August 2013
Certificate of Registration (CoR)	
Issuing Authority:	UAE General Civil Aviation Authority
Issue Date:	7 November 2007 (first issue)
Maximum Take Off Weight (MTOW):	380,000 Kg
Maximum Landing Weight (MLW):	265,000 Kg
Engines:	Four High-bypass Turbofan, Rolls-Royce TRENT 500
No. 1 Engine	
MSN:	71482
TSN:	26,223:30 Hours
CSN:	2,830 Cycles
Time Since Overhaul (TSO):	26,223:30 Hours
Cycles Since Overhaul (CSO):	2,830 Cycles
No. 2 Engine	

MSN:	71265
TSN:	23,102:50 Hours
CSN:	2,736 Cycles
TSO:	23,102:50 Hours
CSO:	2,736 Cycles
No. 3 Engine	
MSN:	71606
TSN:	15,330:40 Hours
CSN:	1,565 Cycles
Time Since Overhaul (TSO):	15,330:40 Hours
Cycles Since Overhaul (CSO):	1,565 Cycles
No. 4 Engine	
MSN:	71542
TSN:	15,936:26 Hours
CSN:	1,695 Cycles
Time Since Overhaul (TSO):	15,936:26 Hours
Cycles Since Overhaul (CSO):	1,695 Cycles



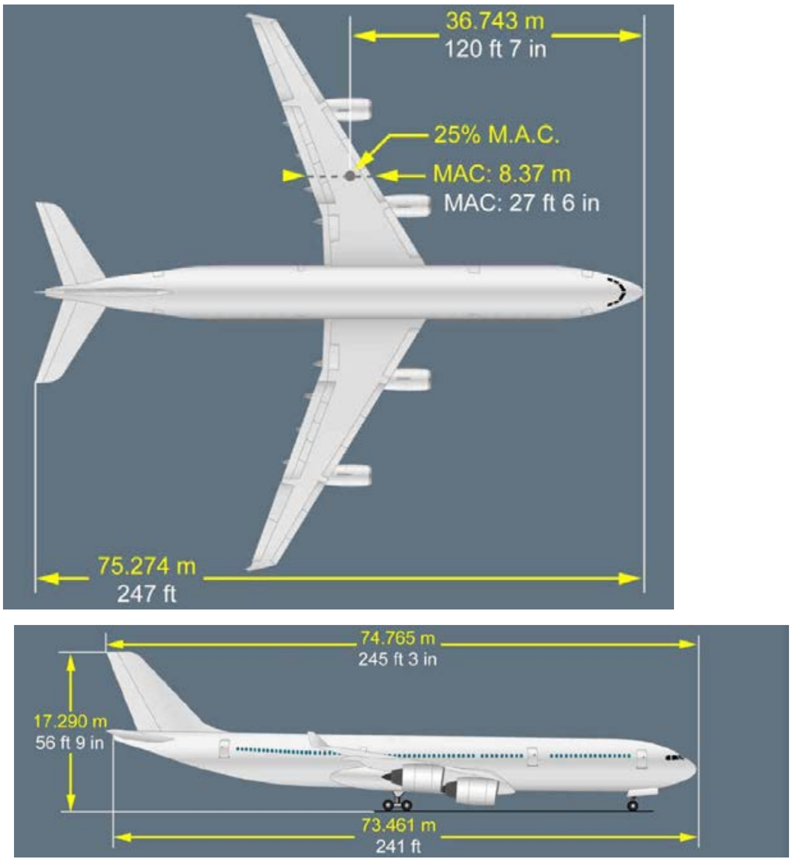


Figure 1. 3-View Drawing of A340-600

1.6.2 Weather Radar

The Aircraft was equipped with a single-function (weather detection) weather radar.

The basic operational principle of the weather detection radar is based on reflectivity of microwave pulses by water droplets. The intensity of the weather echo is linked to droplet size, composition, and quantity (e.g. the reflection of water particles is five times greater than ice particles of the same size). The crew must be aware that the weather radar does not detect weather that has small droplets (e.g. clouds or fog), or that does not have droplets (e.g. clear air turbulence).

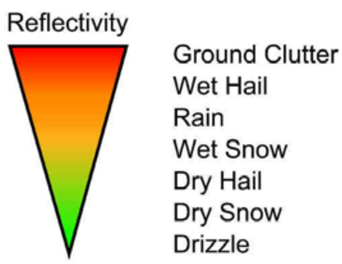


Figure 2. Weather Radar Reflectivity

When the radar is operating, and when the navigation display (ND)[22] is not in PLAN mode[23], the ND displays the weather radar picture. The echoes appear in different colors, depending on the precipitation rates (black, green, yellow, red or magenta). The selected ND range determines how often the image is refreshed.

The tilt angle appears in blue in the lower right-hand corner of the screen along with MAN (Manual) indication. The value of the tilt angle is shown in degrees, as shown in Figure 3.

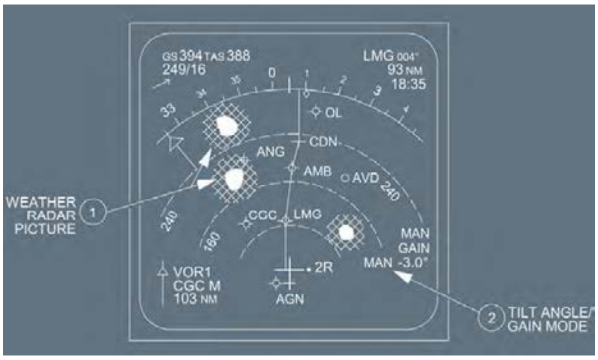


Figure 3. Weather Radar Display

The tilt refers to the angle between the horizon and the radar beam axis (antenna), as shown in Figure 4. The radar uses the aircraft inertial reference system (IRS) data to stabilize its antenna. Consequently, antenna tilt is independent of the aircraft pitch and bank angles.

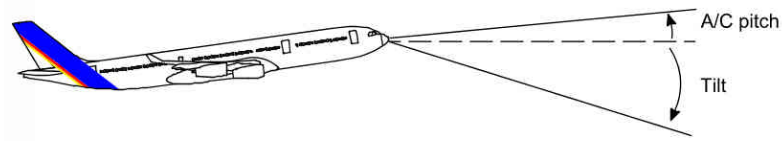


Figure 4. Weather Radar Antenna Tilt Angle

The installed weather radar on the Aircraft was neither equipped with an auto-tilt function which would set the tilt of the beams automatically according to the altitude of the aircraft, nor an auto-scanning function which would continuously scan both vertically and horizontally along the intended trajectory of the aircraft, to optimize weather radar detection.

To ensure efficient weather monitoring, the flight crew must effectively manage the antenna tilt angle, taking into account the flight phase and the ND range. Usually, the appropriate tilt value provides ground returns on the top of the ND.

[22] The electronic flight instrument system (EFIS) displays mostly flight parameters and navigation data on the primary flight displays (PFDs) and navigation displays (NDs)

[23] This mode statically displays the flight plan legs on a map oriented to true north.

At high altitude, a cell may contain ice particles whose reflection is usually weak. Therefore, an incorrect tilt angle may lead to scanning of only the upper (less reflective) part of a cell. Consequently, a cell may not be detected, or may be underestimated.

The flight crew usually uses the GAIN knob to adjust the color intensity of the displayed weather. In standard operation, the flight crew should set the GAIN knob to AUTO (Automatic). The flight crew can manually tune the GAIN to analyze cells. To detect the strongest part of a cell, displayed in red on the ND, the flight crew can slowly reduce the GAIN. The red areas will slowly become yellow areas, and the yellow areas will become green areas. The last part of the cell to turn yellow is the strongest area. After a cell analysis, the flight crew should reset the GAIN knob to AUTO.

When manual GAIN mode is selected, “MAN GAIN” appears on the screen in white.

The flight crew can use the turbulence detection mode (TURB selector set to AUTO) to locate wet turbulence areas within 40 nm of the aircraft.

1.6.3 Airspeed Measuring System

The Airbus A340-600 has three independent systems to provide airspeed and altitude data: the captain, F/O and standby systems.

The airspeed is measured by comparison of the total pressure by means of a pitot probe, and the static pressure by means of two static ports. The aircraft has three pitot probes, and six static pressure ports/sensors. All three pitot probes installed on the Aircraft were manufactured by Goodrich and designated model 0851HL.

The probes are electrically heated to prevent ice build-up during flight, and they are fitted with drain holes to remove water and/or ice following de-icing. The probes are automatically controlled and monitored by three independent Probe Heat Computers (PHCs). Each PHC protects the probe from overheat and can indicates any faults.

In addition to the pitot probes and static ports, the A340-600 has two Total Air Temperature (TAT) and three Angle of Attack (AOA) sensors.

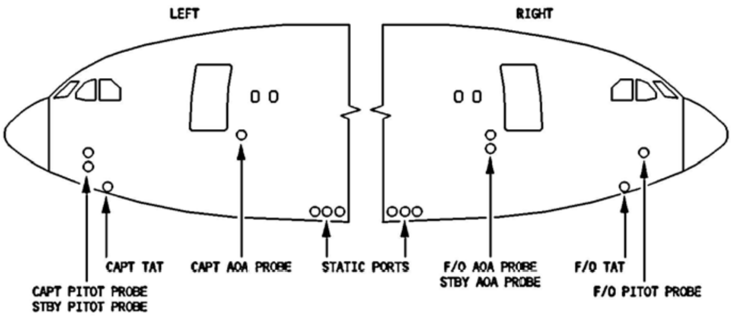


Figure 5. Measuring System

Pneumatic air pressure measurements from the pitot probes and static ports are converted into digital electrical signals by eight Air Data Modules (ADMs). The Aircraft was fitted with Honeywell manufactured ADMs, part number PG1152BC02.

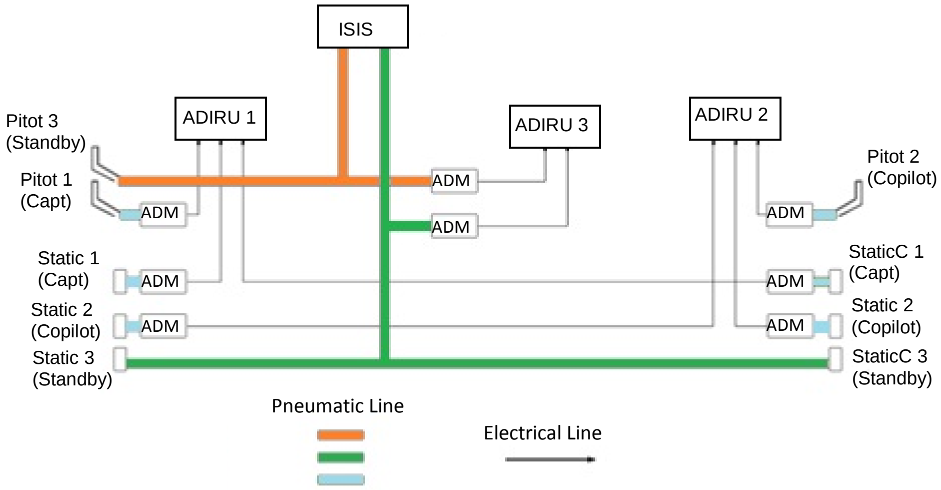


Figure 6. Airspeed and Altitude Measurement

The main parameters of airspeed information used by the pilots and the various aircraft systems are the Computed Air Speed (CAS) and the Mach Number (M). Three Air Data Inertial Reference Unit (ADIRU) computers provide both parameters.

The Aircraft was fitted with three Honeywell manufactured model HG2030AE23 ADIRUs. Each ADIRU has two separate modules: an Air Data Reference (ADR) module, which calculates the aerodynamic parameters such as static air temperature, TAT, AOA, altitude, calibrated airspeed and Mach Number; and an Inertial Reference (IR) module which provides parameters delivered by the inertial units, such as attitude and ground speed.

Therefore, the Aircraft had three airspeed information systems which function independently. A set of one pitot probe and two static ports which are dedicated to the "captain probes" deliver ADR1, while the "F/O probes" set delivers ADR2, and the "standby probes" set delivers ADR3.

The CAS is displayed on the captain's PFD (PFD1) from ADIRU1, on the F/O PFD (PFD2) from ADIRU2, and on the standby instrument known as the Integrated Standby Instrument System (ISIS).

The ISIS determines its airspeed and altitude information directly from the pneumatic inputs of the "standby probes" without being processed by ADMs or an ADR module. The ISIS is a standby instrument that integrates airspeed, altitude, and aircraft attitude information, which uses the same total and static pressure sensors as ADIRU 3.

The ADIRUs transmit the calculated parameters to various aircraft systems, including: the Flight Management, Guidance and Envelope System (FMGES) and the fly-by-wire flight controls system.

1.6.4 Flight Guidance System

1.6.4.1 Flight Management Guidance and Envelope System – General

The FMGES of the A340-600 has four modes of operation, and uses two Flight Management Guidance and Envelope Computers (FMGECs).

The FMGES modes of operation are Dual Mode (normal mode); Independent Mode (each FMGEC being controlled by its associated Multipurpose Control and Display Unit (MCDU); Single Mode (using one FMGEC only); and Back-up Navigation Mode.

The flight guidance component of each computer controls the FD, AP and A/THR which is connected to a Flight Control Unit (FCU).

FD1 displays the guidance commands from FMGEC1 on the captain’s PFD and FD2 displays the guidance commands from FMGEC2 on the F/O's PFD in normal operation with FD push-buttons lit on the FCU (FD engaged).

FMGEC1 controls the AP1 function and FMGEC2 controls the AP2 function. The A/THR function is controlled by the FMGEC associated with the engaged AP.

The CAS, Mach Number and altitude deviations of all three ADRs are continuously monitored by both FMGECs. At least two ADR outputs must be considered valid for use by the FMGEC. If the computers detect excessive deviation between one ADR output and the outputs of the other two ADRs, then the first ADR output is rejected. If the output of one of the two remaining ADRs is invalid, the AP, A/THR and FD automatically disconnect. The FD will automatically re-engage when its associated FMGEC detects at least two valid and consistent ADR outputs.

When the associated AP and A/THR become available again, the flight crew may re-engage them manually.

1.6.4.2 FMGEC – ADR Monitoring (Auto Flight Disconnection Logic)

The FMGECs continuously monitor the comparison between the three ADR parameters. The deviation limits for the CAS, Mach and Standard Altitude that trigger an ADR rejection are:

- CAS: 20 kts, confirmed in 450 milli second (msec);
- Mach: 0.04, confirmed in 450 msec; or
- Standard Altitude: 400 ft, confirmed in 450 msec

If any of the three parameters is out of tolerance, the FMGEC will reject the associated ADR. This failure is latched by the FMGEC in command (AP ON). When the AP is OFF, and if the parameters return within tolerance, the associated ADR is used again.

On the A340-600 aircraft, compared to the basic A340, a part of the AP logic is performed by the FCPC instead of the FMGEC. Consequently, if the FCPC definitively latches the three ADR rejections, it will be no longer possible to re-engage the AP. In such a case, the “AP 1+2” amber message will be displayed in the “INOP SYS” area of the ECAM STATUS page.

However, if at least two valid ADRs return within tolerance, it becomes possible to re-engage the A/THR and the FDs, as the FD and A/THR logics are still in the FMGEC.

1.6.5 Flight Control System

1.6.5.1 General

The Airbus A340-600 is equipped with fly-by-wire flight controls. The flight control surfaces are electrically controlled and hydraulically actuated. Pilot inputs on the two side-stick controllers and the autopilot inputs are transmitted in the form of electrical signals to flight control computers. The aircraft has three Flight Control Primary Computers (FCPC or PRIM), two Flight Control Secondary Computers (FCSC or SEC), and two Slat/Flap Control Computers (SFCC). The role of these computers is to calculate the position of the various control surfaces as a function of the pilots or autopilot inputs.

The relationship between the input on the side-sticks or autopilot, and the aircraft's flight control surfaces, is referred to as Control Law, which determines the handling characteristics of the aircraft.

There are three sets of control laws: Normal, Alternate and Direct Law, and they are provided according to the status of the computers, peripherals, and hydraulic generation.

Normal Law

Flight control Normal Law provides:

- Pitch control flight mode protection: pitch attitude; load factor; high speed; and high angle of attack
- Lateral control flight mode protection: bank angle
- Flight envelope
- Maneuver load alleviation

The Normal Law flight mode is a load factor demand law with auto trim and full flight envelope protection.

In manual flight, it provides elevator and Trimmable Horizontal Stabilizer (THS) control from the side-sticks to achieve a load factor proportional to stick deflection, independent of speed.

With the AP engaged, it provides elevator and THS control according to the AP and load factor demand. Pitch trim is automatic in both manual and AP mode.

Alternate Law

In some double failure cases, the integrity and redundancy of the computers and the peripherals is not sufficient to achieve Normal Law and its associated protections. System degradation is progressive, and will evolve according to the availability of remaining peripherals, or computers.

In addition, depending on the type of failure, the Control Law may be either Alternate 1 (ALTN1) or Alternate 2 (ALTN2).

Alternate Law characteristics (usually triggered in case of a dual failure):

- In pitch: same as Normal Law
- In roll: same as in Normal Law (ALTN1), or Roll Direct (ALTN2)

- In yaw: same as in Normal Law (ALTN1), or degraded (ALTN2)
- Most protections are lost, except:
  - Load factor protection
  - Bank angle protection, if normal roll is still available (ALTN1 only).

At the flight envelope limit, the aircraft is not protected:

- In high speed, natural aircraft static stability is restored with an overspeed warning
- In low speed (at a speed threshold that is below VLS), the automatic pitch trim is not available, and natural longitudinal static stability is restored, with a stall warning whose threshold depends on the aircraft configuration and the Mach.

In certain failure cases, such as the loss of VS1G computation, or the loss of two ADRs, the longitudinal static stability cannot be restored at low speed. In the case of a loss of three ADRs, it cannot be restored at high speed.

In Alternate Law, maximum operating speed or Mach (VMO/MMO) settings are reduced, and α FLOOR [24] protection is inhibited.

Direct Law

In most triple failure cases, direct law is triggered. When this occurs:

- Elevator deflection is proportional to stick deflection. Maximum deflection depends on the configuration and on the CG
- Aileron and spoiler deflections are proportional to stick deflection, but vary with the aircraft configuration
- Pitch trim is commanded manually
- Yaw damper and minimum turn coordination are provided.

1.6.5.2 FCPC – ADR Monitoring (Flight Control Monitoring)

1.6.5.2.1 ADR Speeds Comparison Monitoring

Among other parameters, the FCPC monitors the three ADR speeds emitted by the ADRs through a comparison to the median. The thresholds on the CAS for an ADR rejection are:

- In case three ADR speeds are valid: 16 kts confirmed in 10 seconds
- In case only two ADR speeds are valid: 16 kts confirmed in 1 second

If the two remaining ADR speeds are rejected through comparison, after a first one has already been rejected, the message “NAV ADR DISAGREE” is triggered. Any rejection of an ADR is definitively latched until the end of the flight. If all three ADRs are rejected, the Flight Control reverts to Alternate Law.

[24] ALPHA (α) FLOOR protection is triggered when the FMGECs receive a signal elaborated by the FCPCs. This signal is sent when the aircraft’s angle of attack is above a pre-determined threshold function of the aircraft’s configuration.

Note: An ADR is also rejected as soon as one of its monitored parameters is other than “Normal Operation” (NO).

1.6.5.2.2 Icing Monitoring

Icing monitoring is performed by the FCPC on CAS parameter through a vote.

In case of pitot obstruction, if voted CAS drops by more than 30 kts within 1 second, the three ADR will not be used anymore by FCPC during 10 seconds, F/CTL reverts to Alternate Law, and the icing monitoring is triggered.

- If three ADR speeds are valid, the voted CAS is the median value
- If two ADR speeds are valid, the voted CAS is the average value

After 10 seconds, voted CAS is compared to the voted CAS recorded just before pitot obstruction. If the difference is lower than 50 kts, the three ADRs are used again and the higher available F/CTL law is engaged.

If the difference is greater than 50 kts, the three ADR speeds are considered lost by the FCPC until the end of the flight, and the message “PROBE PITOT 1+2/2+3/1+3 (9DA)” is recorded on the PFR.

Note: On A330 and basic A340, the message “F/CTL RUD TRV LIM FAULT” will trigger.

1.6.6 Ice Detection System

An ice detection system is installed on the Aircraft, which has two separate ice detector probes on the forward lower section of the fuselage. The system operates automatically and starts at electrical power up.

The probes detect ice build-up and also indicate, through the MEMO display on the ECAM, that icing conditions are no longer prevalent.

The system logic generates ECAM messages according to ice detector signals, and the flight crew’s selection of engine or wing anti-ice systems.

The ice detection system does not control the ENG or WING anti-ice systems.

Based on the FDR data, both detectors did not detect any ice built-up.

1.6.7 Flight Warning System (FWS)

1.6.7.1 General

The FWS, as shown in Figure 7, uses two identical Flight Warning Computers (FWCs) which generate alert messages, memos, aural alerts, and synthetic voice messages. For this purpose they acquire data:

- directly from aircraft sensors or systems to generate red warnings.
- through the SDACs to generate amber cautions.

The ECAM display units display the alert messages generated by the FWCs.

The FWCs also generate:

- radio altitude callouts.
- decision height callouts.
- landing speed increments.

The FWCs also drive, on each pilot panel under the glareshield:

- the master warning light that flashes "MASTER WARN" in red for red warnings; and
- the master caution light that illuminates "MASTER CAUT" in amber for amber cautions.

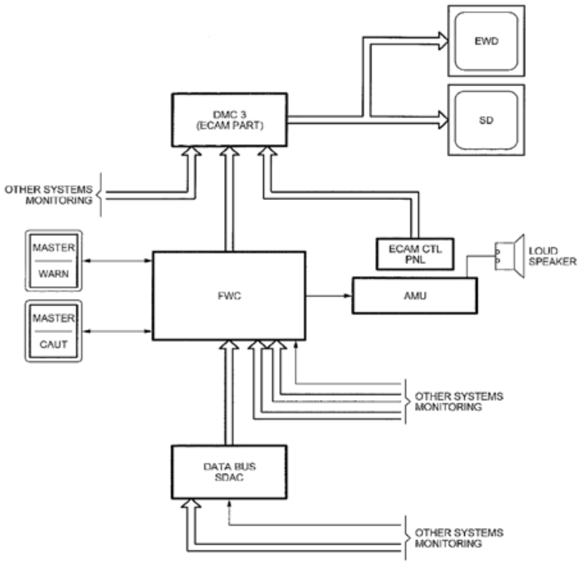


Figure 7. Flight Warning System

1.6.7.2 FWC and ADR Monitoring

When the FCPC monitoring logic detects a CAS discrepancy, it informs the FWC which triggers the "NAV IAS DISCREPANCY" message (recorded in the PFR) if it concerns a CAS currently displayed.

1.6.8 Maintenance

1.6.8.1 Maintenance Records

Based on the maintenance records, there was no evidence that the Aircraft had experienced unreliable airspeed and engine N1 vibration events before this Incident. No discrepancies were found on systems/equipment related to airspeed and altitude indications, and engine vibration for the last one month before the Incident.

Related to Ice Detection

On 25 January 2013, an ICE DETECT FAULT caution was found after landing. The ice detection circuit breaker (C/B) was reset, and an operational check was carried out in accordance with AMM 30-81-00-710-801. The result was satisfactory with no message on ECAM or on Maintenance Status.

On 28 January 2013, an ICE DETECT FAULT caution was found prior to departure. The fault item was deferred based on MEL 30-81-01A Cat D. On 29 January 2013 after one flight, the ice detector probe 2 (RH side) was replaced. A system test was carried out in accordance with AMM 30-81-00-810-804, and found satisfactory. Consequently, the deferred defect was cleared.

1.6.8.2 Inspection and Testing

Related to the unreliable airspeed issue

In relation to the unreliable airspeed issue, inspection/testing of the following systems was performed in Singapore after the Incident flight.

Inspection check of pitot probes was carried out as per Aircraft Maintenance Manual (AMM) 34-11-15-200-801A, and no abnormalities were found.

ADR1, 2, and 3 system tests were carried out, and no fault was found. Based on the ground report, no fault was found related to NAV ADR DISAGREE and ALTN LAW failures.

Functional test of heater insulation resistance of (pitot and AOA) probes was carried out as per AMM 30-31-00-720-802A, and the result was satisfactory.

Duplicate inspection of pitot probes 9DA1, 9DA2 and 9DA3 electrical connectors was performed and found satisfactory.

The Aircraft was ferried back to Abu Dhabi following the above mentioned inspection checks.

On 5 February 2013, inspection of pitot probes was carried out in accordance with AMM 34-11-15-200-801A and no abnormalities were found. ADM1 was replaced in accordance with AMM 34-11-17 PB 401. Then, a BITE test was performed in accordance with 34-13-00-740-803A, and the result was satisfactory. During the replacement of ADM1, a spacer was found missing and a new spacer was installed, and found satisfactory.

Related to N1 vibration of No.2 Engine

Troubleshooting of No. 2 engine was carried out in Singapore relative to the N1 high vibration problem, as follows:

- Detailed inspection of the fan blades, annulus fillers and fan case
- Intermediate Pressure Compressor boroscope inspection
- Engine high power runs

No findings were noted by the above mentioned inspections.

The No. 2 engine Anti Ice Valve was locked in the open position. The item was deferred based on MEL 30-21-01B Cat C. Subsequently, the Aircraft was ferried back to Abu Dhabi International Airport (OMAA) without passengers onboard.

After the Aircraft returned to Abu Dhabi, the Anti-ice pressure regulator valve of No. 2 engine was replaced, in accordance with AMM 30-21-51 PB 401. An engine ground run operational check was carried out and the engine operated normally. A detailed visual inspection of the installation of clamps and seals upstream and downstream of the valve was performed, and found satisfactory. Consequently, the deferred defect of the open position of the locked No. 2 engine Anti Ice Valve was cleared.

Further examination was conducted by removing the subject engine from service, and analysis was made by the engine manufacturer. The following observations were noted during this examination:

- The spinner fairing revealed signs of lifting on 9 dimple washers [item 232] and clearance was noted between the spinner fairing and the inlet cone.

Figure item
[085] Nose Cone
[152] Omega Seal
[220] Nose Cone Fairing
[232] Washer
[238] Band

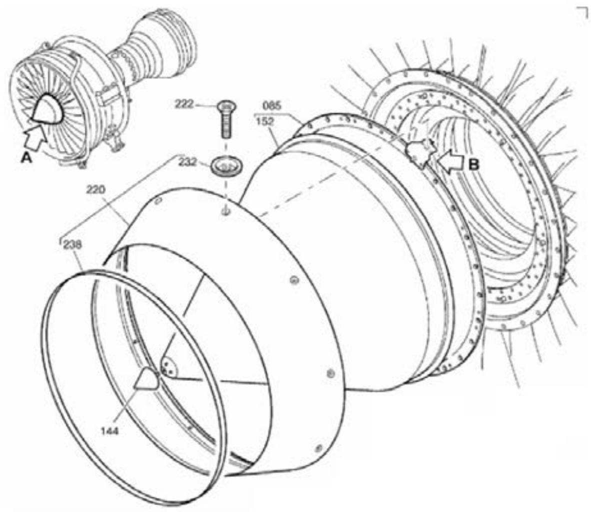
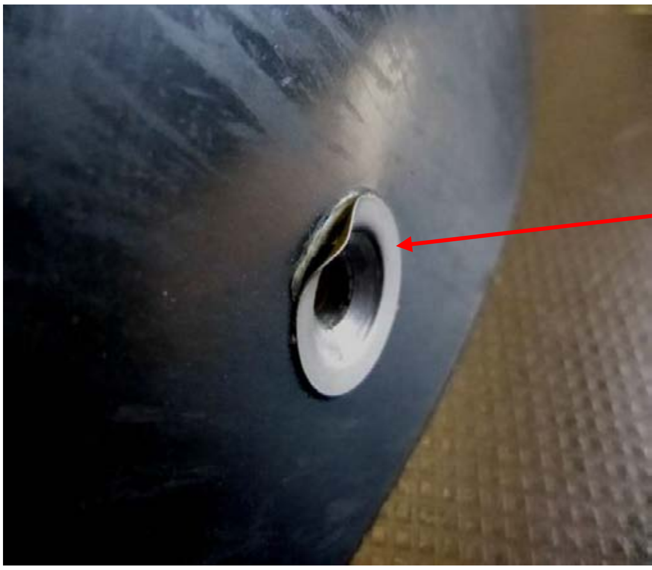


Figure 8. Air Intake Fairing/Spinner

- Three of the dimpled washers were missing and all others distorted on the Nose Cone Fairing, as shown in Figure 9.

Washer [Item 232]

Missing Washer



Distorted Washer

Figure 9. Washers Condition

- Outer surface the omega Seal was in disband condition which made the omega seal loose on the Nose Cone, as shown in Figure 10.

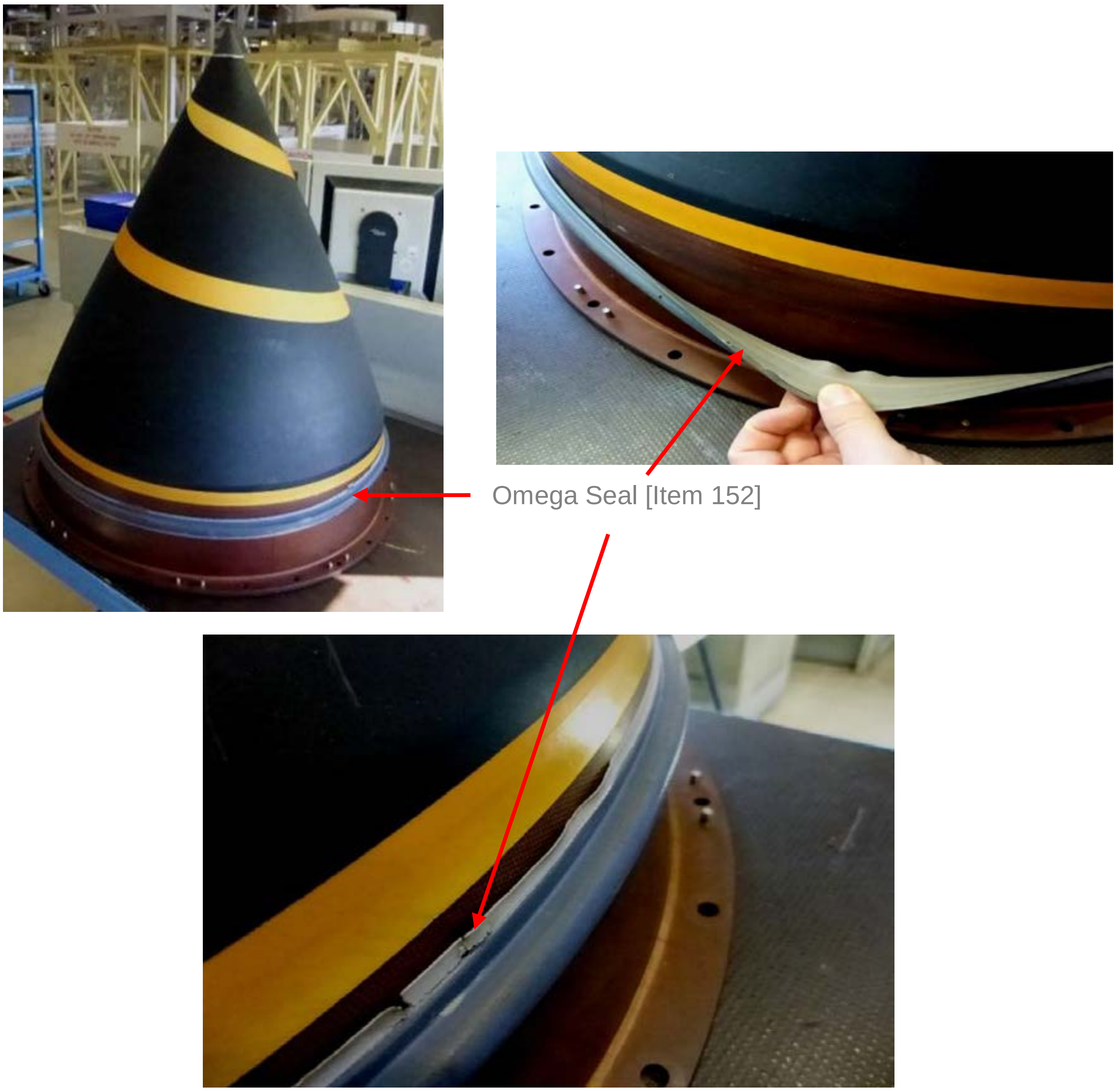


Figure 10. Omega Seal Condition

In Maintenance Planning Document (MPD), task 723100-R6-1 "RE-LUBRICATION OF LP COMPRESSOR BLADE ROOT COATINGS", requested to be performed every 1200FC, requires spinner removal. At this opportunity, any damage on omega seal can be detected.

Related to Ice Detection

On 4 February 2013, after the ferry flight back to Abu Dhabi, the ice detector probe 1 (LH side) was replaced. A BITE test of ice detection was carried out in accordance with Trouble Shooting Manual (TSM) 30-81-00-810-803-A, and found satisfactory.

1.6.8.3 Maintenance System – Post-Flight Report

The Aircraft has a Central Maintenance System (CMS) to ease the maintenance task by directly indicating, in the cockpit, the fault messages and allowing some specific tests. One Central Maintenance Computer (CMC) is used for the CMS. The CMS records, and displays, the failure messages permanently transmitted by each system's Built-In Test Equipment (BITE).

The Post Flight Report (PFR) presents all ECAM warning/caution and failure messages recorded during the Incident flight leg. The PFR is printed after engine shutdown.

The PFR of the Incident flight was obtained after the Aircraft landed in Singapore which contained a number of cockpit effect messages relevant to the event. In Appendix 1, the table shows the cockpit effect messages and the related systems.

The PFR data of the Incident flight did not show any failure of the Probe Heat Computers.

1.6.9 Engine

1.6.9.1 General

The four (4) Rolls-Royce (RR) TRENT 500 engines installed on the aircraft, as shown in Figure 11, are three-spool high bypass turbofan engines.

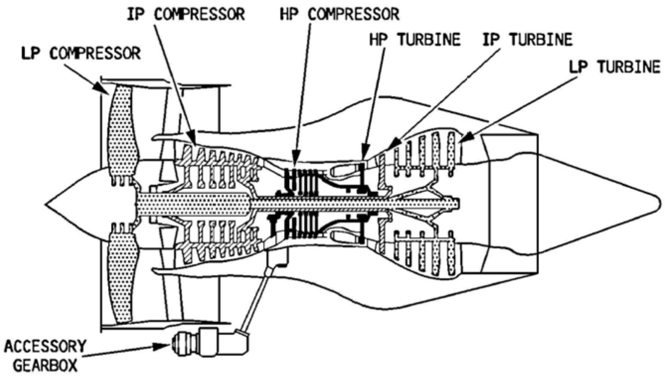


Figure 11. RR TRENT 500 Engine

Low-pressure (LP) compressor/turbine

The low-speed rotor (N1) consists of single stage LP compressor (front fan) connected to a five stage LP turbine.

Intermediate pressure (IP) compressor / turbine

The intermediate speed rotor (N2) consists of eight-stage intermediate pressure compressor connected to a single-stage IP turbine.

High-pressure (HP) compressor / turbine

The high-speed rotor (N3) consists of a six-stage HP compressor connected to a single-stage HP turbine.

Combustion chamber

The annular combustion chamber is fitted with 20 fuel nozzles and 2 igniters.

Accessory gearbox

The accessory gearbox, located at the bottom of the fan case, receives torque from the horizontal HP rotor drive shaft and drives the gearbox-mounted accessories.

The engine primary parameters are permanently displayed on the upper ECAM Engine/Warning and Display (E/WD).

The secondary parameters are displayed on the lower ECAM system display (SD), when selected either automatically or manually.

Vibration (VIB) indication is a secondary engine parameter and is indicated in green. It pulses in case of an advisory in flight if N1 VIB is higher than 2.8 units, or 3.6 units with engine anti-ice On (ENG ANTI ICE ON). If VIB indication is not displayed, the ENGINE system page is automatically called up, in case of a vibration advisory.

1.6.9.2 N1 Vibration on No.2 Engine

Based on FDR parameters and PFR data, the N1 vibration of No. 2 engine (N1V2) showed that:

- Between 00:51:20 and 00:52:04, N1V2 increased from 0.2 to 1.6 units and returned back to 0.3 units.
- Between 00:52:16 and 00:54:07,
    - N1V2 continuously increased from 0.3 units to a maximum of 7.1 units.
    - Advisory of N1 vibration on No. 2 engine became active at 00:52:59 (on the PFR at time 00:53: ADVISORY ENG2 N1 VIBRATION), when N1V2 was 3.8 units.
- The advisory of N1 vibration of No. 2 engine indicated alternately from active to off continuously for about 1 hour and 20 minutes (from the time 00:54:43 until 02:14:21).

1.6.10 Engine Ice Protection

The Aircraft is equipped with engine ice protection, as given in Figure 12. An independent air bleed from the high pressure compressor protects each engine nacelle from ice accretion. The bleed air is supplied through a two-position (open and closed) valve that the flight crew controls with pushbuttons, one for each engine. When an engine anti-ice valve is open, the N1 limit for that engine may be automatically reduced, and the idle N1 is automatically increased. If electric power fails, the valves open.

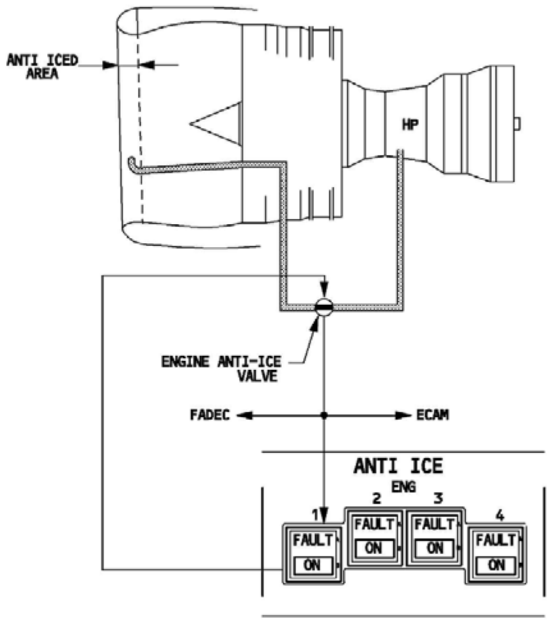


Figure 12. Engine Ice Protection

Operating pushbuttons of the engine Ice protection:

ON Light: Comes on in blue.

The ENG A.ICE message appears on the ECAM MEMO display.

The engine anti-ice valve opens.

OFF Light: The ON light goes off.

The engine anti-ice valve closes.

FAULT Light: Comes on in amber, with an ECAM caution, if the position of the anti-ice valve disagrees with the ENG pb sw selection.

Note: The amber FAULT light comes on briefly, while the valve transits.

1.7 Meteorological Information

The dispatch documents provided to the flight crew included a fixed time prognostic chart of the Indian Ocean valid for 00:00 UTC, 3 February 2013 from FL 250 to FL 630, as shown in Figure 13. This chart was forecasted about 49 minutes before the Incident occurred. The chart included the flight route plan, and indicated an area of isolated embedded cumulonimbus clouds up to FL 450, in the area where the Incident occurred. This was just before the PIPOV waypoint, and just after passing into the Melbourne FIR from the Colombo FIR.

The area of isolated embedded cumulonimbus clouds stretched longitudinally from approximately 68˚E to 99˚E and latitudinally from approximately 19˚S to 0˚ (equator line). The red point mark indicates the Aircraft position at the commencement of the Incident, whereas the red line indicates the diversion towards Singapore Changi International Airport.

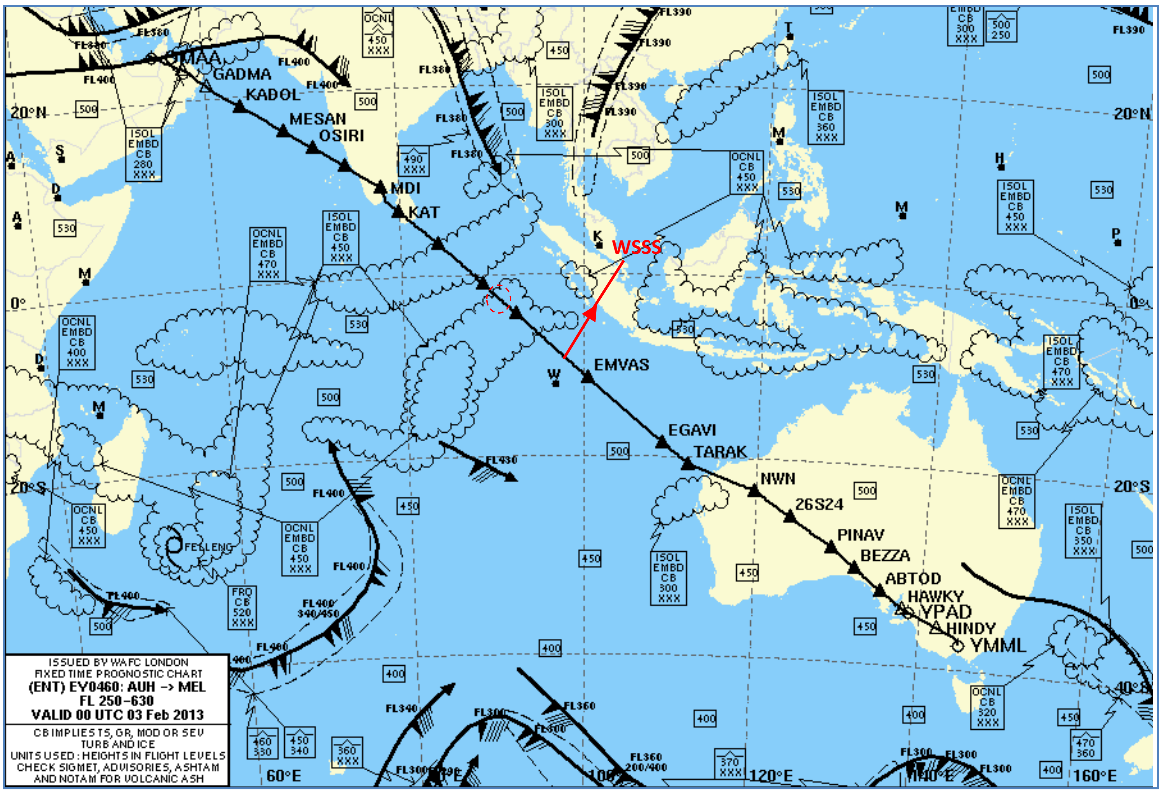


Figure 13. Fixed time prognostic chart of the Indian Ocean valid for 00:00 UTC, 3 February 2013 from FL 250 to FL 630

A color satellite image of the area, as given in Figure 14, was taken at 16:30 UTC of 2 February 2013 and was also provided in the dispatch package. This image was taken about 8 hours 20 minutes before of the Incident. The image indicated an area of intense convective activity from approximately 5^0N down to the equator latitudinally, and from approximately 86^0E to 92.5^0E longitudinally.

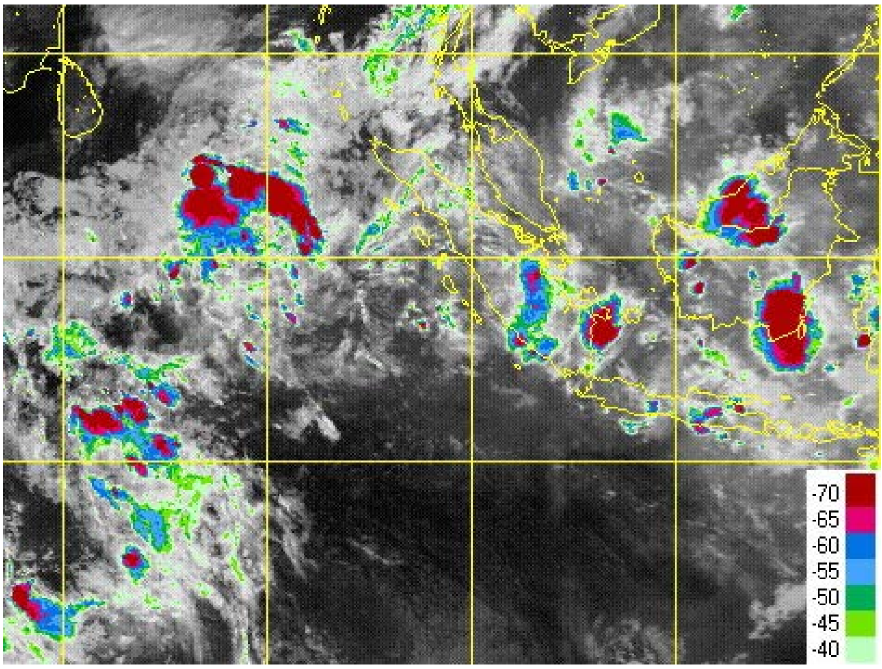


Figure 14. Satellite Image

A fixed time prognostic chart of the Indian Ocean, as given in Figure 15, was valid for 18:00 UTC, 2 February 2013 from FL 250 to FL 630. This chart indicated an area of isolated embedded cumulonimbus clouds up to FL 450. Comparing with the previous fixed time prognostic chart for 00:00 UTC, 3 February 2013 (6 hours thereafter) as shown in Figure 13, the embedded CBs were not so much different in size and position. Therefore, it is considered that at the time of the Incident, the area of the intense convective activity was not too different with the one as shown in Figure 14, the color satellite image taken at 16:30 UTC of 2 February 2013. At this time, as shown, the Aircraft was flying through the area where the intense convective activity was present.

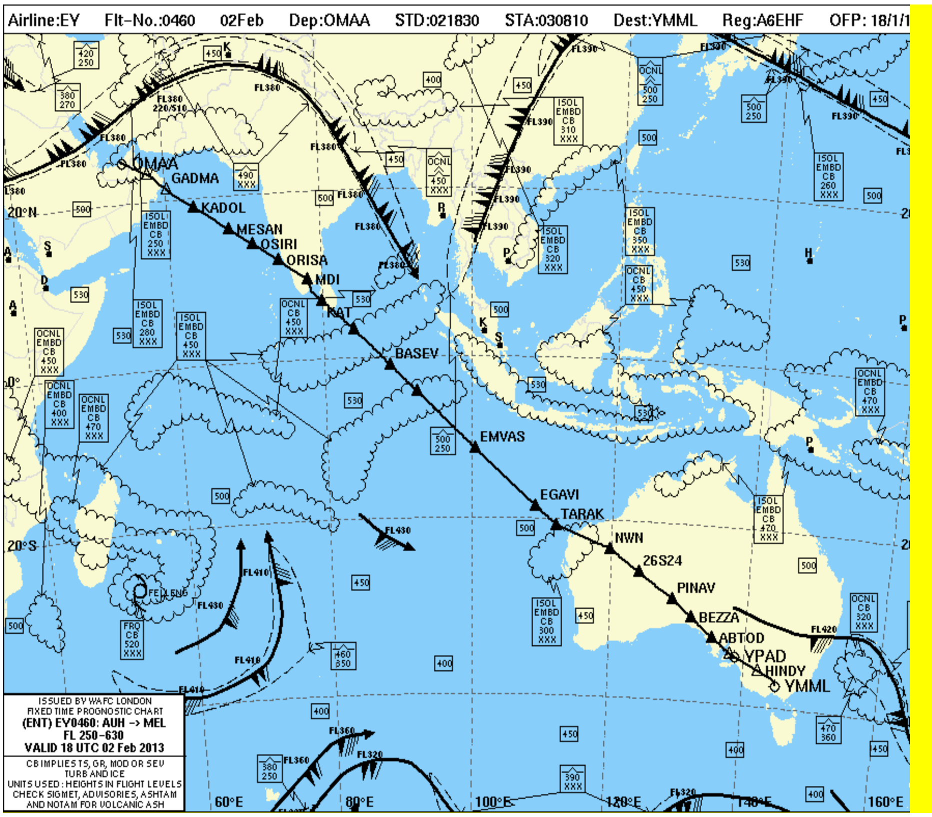


Figure 15. Fixed time prognostic chart of the Indian Ocean valid for 18:00 UTC, 2 February 2013 from FL 250 to FL 630

1.8 Aids to Navigation

The aids to navigation became a factor after the Incident since the Aircraft experienced the disengagement of the autopilot, which remained disengaged for the diversion to Singapore, and resulted in loss of RVSM capability.

The captain performed an uneventful standard instrument landing system (ILS) approach and landing on RWY 02L at Singapore.

1.9 Communications

Shortly after the Incident, the flight crew attempted unsuccessful HF communication with both Brisbane and Melbourne ATC. Accordingly, the crew transmitted an emergency message via the CPDLC to Melbourne ATC reading: “PAN PAN unable maintain altitude due to A/C perform, weather, turbulence”; and “Aircraft’s loss of RVSM capability”. Melbourne ATC replied via the same channel about 20 minutes later, and provided clearance to the Aircraft to divert to Singapore.

The Satellite Communication (SATCOM) was used to communicate with the Operator’s MCC and NOC to obtain technical and operational assistance and to coordinate for the diversion. SATCOM was also used to inform the Operator’s NOC of the decision to divert.

The flight crew established communication with Jakarta ATC in order to obtain authorization to jettison fuel before descending towards Singapore.

The communications between the Aircraft and the Changi Airport Approach and Tower were normal.

1.10 Aerodrome Information

The aerodrome was not a factor in this Incident.

1.11 Flight Recorders

1.11.1 General

The Aircraft was equipped with a Cockpit Voice Recorder (CVR), a Digital Flight Data Recorder (DFDR) and a Digital ACMS Recorder (DAR)[25].

The DFDR was manufactured by L-3 Comm, (P/N 2100-4043-02 and S/N 000285751). The DFDR was taken to the Flight Recorder Laboratory at the GCAA Headquarters in Abu Dhabi for download and analysis. The Investigation retrieved useful information from the DFDR.

The DAR information was retrieved by the Operator as part of their Flight Data Monitoring (FDM) program. The data provided valid information, and that was used in the analysis.

The CVR recorded the final 120 minutes of the flight. Since the diversion flight time from the Incident location until the Aircraft landed at Singapore was approximately three hours, the information pertaining to the Incident was not captured.

1.11.2 Read-out and Event Descriptions of the FDR and DAR data

Relevant read-out and event descriptions from the FDR and ADR data were examined with the assistance of the Manufacturer.

1.11.2.1 Unreliable Airspeed of CAS1 and ISIS_CAS (CAS3)

The following is a summary of the unreliable airspeed indication read out and event descriptions. More detailed descriptions can be found in Appendix 2. Figure 16 shows the unreliable airspeed indications and the summary of the effect on the systems.

First fluctuation/unreliable Airspeed Indication

Between 00:50:04 and 00:50:09, CAS1 decreased to an out of tolerance value, and ADR1 was rejected by the FMGEC. Both CAS2 and ISIS_CAS (CAS3), out of the three CAS values remained valid and consistent, which allowed AP1 and A/THR to remain engaged. Both FDs remained engaged, and the flight controls were still in Normal Law.

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[25] Digital ACMS Recorder (DAR) is labeled by Airbus rather than Quick Access Recorder (QAR), when a separate Data Management Unit (DMU) is used. QAR is an optional non-crash protected recorder that operators can install to provide access to flight data. Typically, QAR is used by operators to improve flight safety and operational efficiency in their flight operational quality assurance program. ACMS stands for Aircraft Condition Monitoring System.

At 00:50:10, the CAS 1 value increased again and returned within tolerance in one second. All three ADRs were now valid again.

Between 00:50:11 and 00:50:15, CAS1 and ISIS_CAS (CAS3) values were out of tolerance, and all three CAS values were different, which caused the rejection of all three ADRs by the FMGEC and the FCPC.

Based on the FMGEC-ADR monitoring data (auto flight disconnection logic), the rejection of all three ADRs resulted in the automatic disconnection of both flight directors (FD1 and FD2), and the triggering of master warnings, automatic disconnection of AP1 which triggered the message "AUTO FLT AP OFF" on the ECAM, and loss of A/THR which triggered the message "AUTO FLT A/THR OFF".

Based on the FCPC-ADR monitoring data (flight control monitoring), the rejection of all three ADRs, resulted in the flight control law transitioning from Normal Law to Alternate Law at 00:50:14, and this triggered the message "F/CTL ALTN LAW" on the ECAM. Alternate Law was temporarily active (until 00:50:22). These facts are consistent with the triggering of the icing monitoring that occurred at approximately 00:50:12, when the three CAS values were different.

Between 00:50:16 and 00:50:18, the CAS1 value returned and stayed within tolerance, while the CAS3 value remained out of tolerance. As a result, ADR1 and ADR2 were used again by the FMGEC since the CAS1 value had returned within tolerance, and the CAS2 value had remained within tolerance. This allowed both FD1 and FD2 to re-engage automatically.

ADR1 and ADR2 were now valid again as determined by the ADR speeds comparison monitoring.

At 00:50:22, the CAS3 value increased and returned within tolerance. As a result, all three ADRs were again valid, and were used by the FMGEC and FCPC. Consequently, the flight control law returned to Normal Law following the Alternate Law reversion. A/THR was re-engaged at 00:51:02. At this time, the AP could have been re-engaged. However, the AP was not re-engaged by the flight crew.

Second fluctuation/unreliable Airspeed Indication

Between 00:51:04 and 00:51:07, the CAS1 value became out of tolerance for approximately one second and then returned within tolerance. Consequently, ADR1 was rejected by the FMGEC for approximately one second. Then, the three ADRs again became valid and were used.

Both FDs remained engaged as two CAS (CAS2 and CAS3) values out of three remained stable during the temporary ADR1 rejection.

Third fluctuation/unreliable Airspeed Indication

Between 00:51:11 and 00:51:22, the CAS1 value reduced and became out of tolerance for more than 10 seconds. Consequently, ADR1 was rejected by the FMGEC and the FCPC. The rejection of ADR1 by the FCPC was latched through the monitoring of the ADR airspeeds comparison.

Between 00:51:23 and 00:51:30, ADR1 was accepted again by the FMGEC as the CAS1 value increased and remained within tolerance. However, the rejection of ADR1 had already been latched by the FCPC.

At this time the CAS3 value was continuously reducing, and at 00:51:28, due to the discrepancy in the CAS2 and CAS3 values, the FCPC rejected ADR2 and ADR3.

The triggering of the message "NAV ADR DISAGREE", as recorded on the PFR, means that the rejection of the three ADRs by the FCPC, and the flight control reversion to Alternate Law, occurred through the airspeeds data comparison monitoring, at 00:51:28.

The rejection of all three ADRs was latched by the FCPC until the end of the flight, which resulted in it becoming no longer possible to re-engage the autopilot.

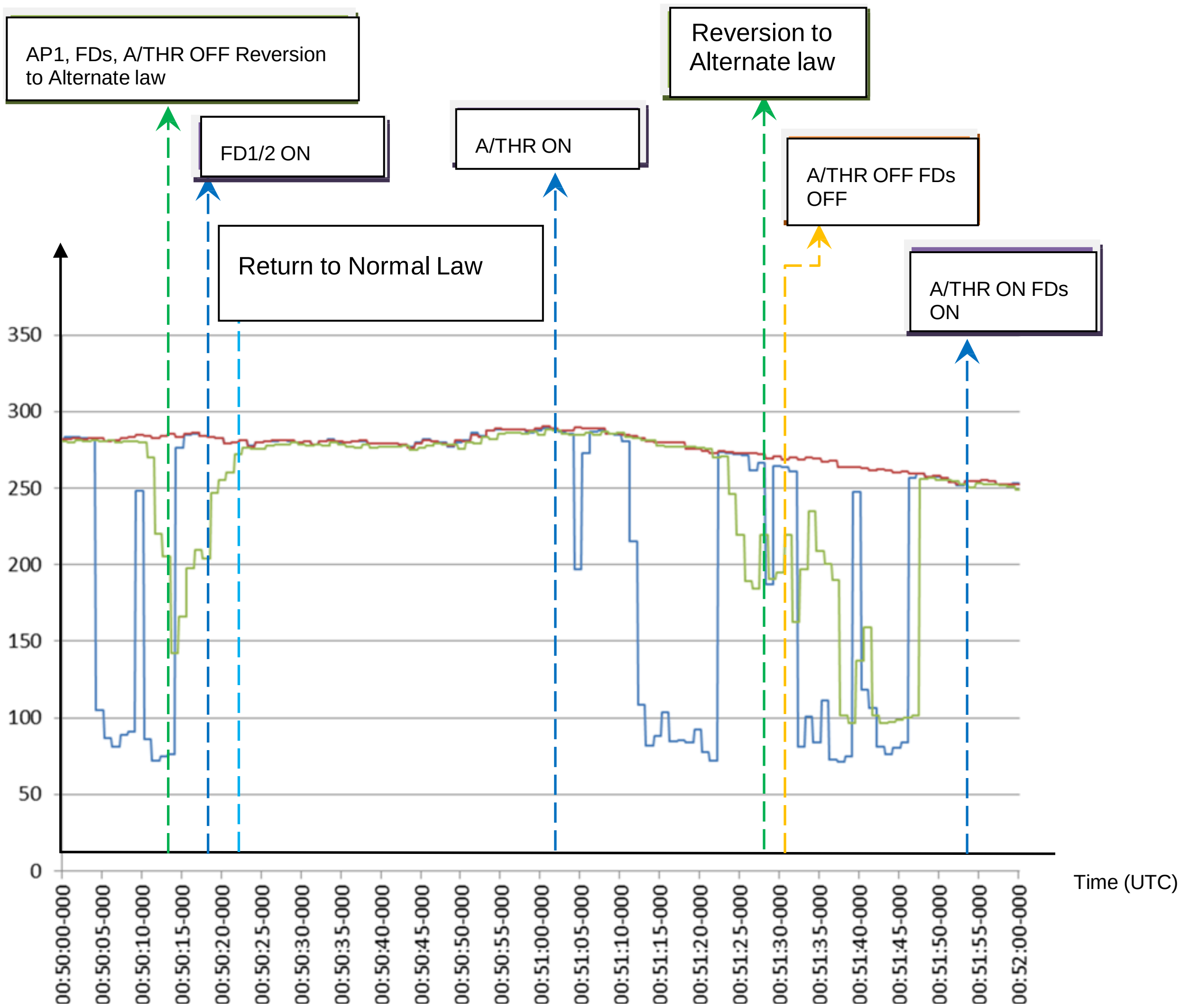


Figure 16. Flight Data Summary

The total duration of the three airspeed indication fluctuations was approximately one minute and forty three seconds.

Before the event, the static temperature was -42^0C or in standard atmosphere the condition was at about ISA+13^0C. The turbulence was described as relatively light to medium. The recorded normal accelerations were between 0.72 and 1.25g. No stall warnings were experienced during the Incident.

1.11.2.2 N1 Vibration on No.2 Engine

Based on FDR parameters and PFR data, as given in Figure 17, the N1 vibration of No.2 engine (N1V2) showed that:

- Between 00:51:20 and 00:52:04, N1V2 increased from 0.2 CU to 1.6 CU and then returned to 0.3 CU.
- Between 00:52:16 and 00:54:13,
  - N1V2 continuously increased from 0.3 CU to a maximum of 7.1 CU.
  - Advisory of N1 vibration on Engine 2 became active at 00:52:59 (on the PFR at time 00:53: ADVISORY ENG2 N1 VIBRATION), when the N1V2 value was 3.8 CU.
- Between 02:30:32 and 03:22:10, the vibration started to decrease to 1.1 CU, as the Aircraft descended from FL350 to FL290.
- At 03:22:11, the vibration ceased as the Aircraft descended from FL290 to FL100.

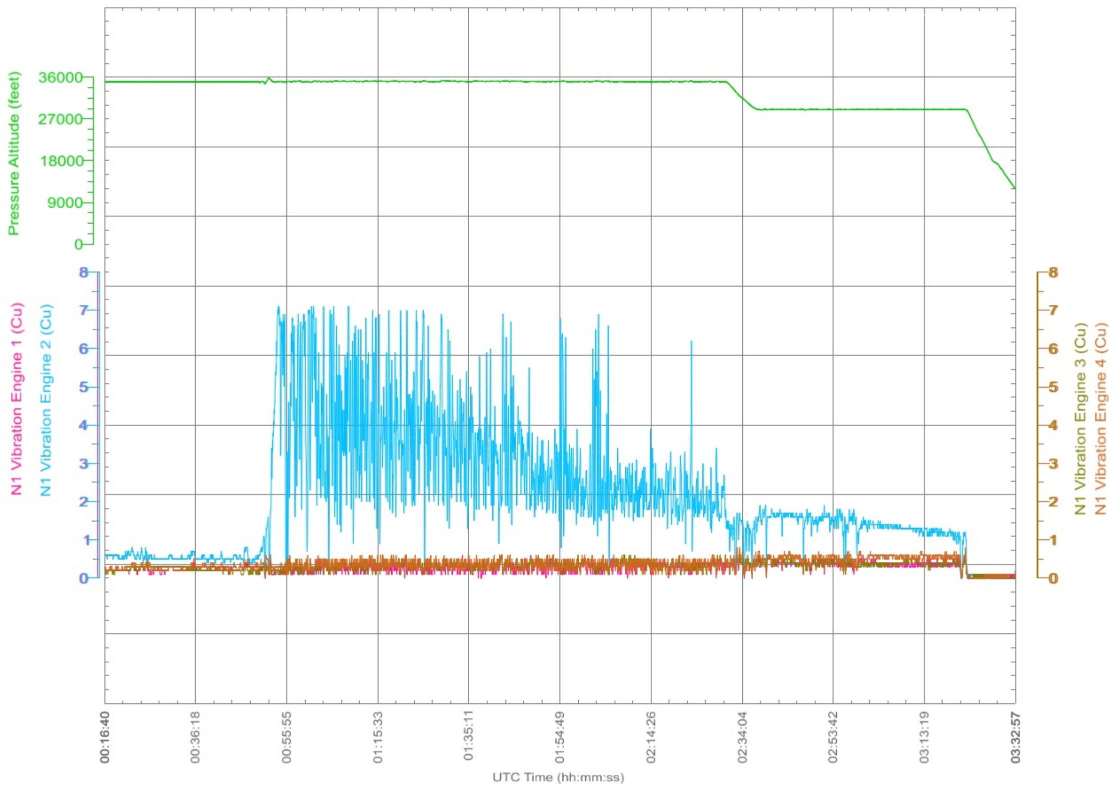


Figure 17. N1 Vibration Data on No.2 Engine

1.12 Wreckage and Impact Information

The Aircraft was undamaged.

1.13 Medical and Pathological Information

No medical or pathological investigations were conducted as a result of the Incident, nor were they required.

1.14 Fire

There was no evidence of fire.

1.15 Survival Aspects

None of the persons onboard sustained any injury.

1.16 Tests and Research

No tests or research were required to be conducted as a result of this Incident.

1.17 Organisational and Management Information

1.17.1 General

The Operator was established by Royal (Amiri) Decree in July 2003 and commenced commercial operations in November 2003. The Operator is the third largest airline in the Middle East, and its main base is Abu Dhabi International Airport.

1.17.2 Training

Unreliable airspeed and dual ADR fault are included in the Operator's A340 First Type Rating Course, Conversion Course, and Recurrent Training.

The subject was covered at least once every three years in the recurrent training program, in accordance with the Operator's *Operations Manual- Part D*.

A manufacturer briefing and presentation on Unreliable Airspeed Procedure, and the use of the Back-up Speed Scale was provided on *Skybook*[26] for pilot self-study.

Based on the training records, all flight crew had attended the required training which included unreliable airspeed indication and dual ADR fault training as per the *Operations Manual- Part D*.

The Operator also published a *Flight Crew Training Manual (FCTM)* as a supplement to the *Flight Crew Operating Manual (FCOM)*, which was designed to provide pilots with practical information on how to operate the Airbus A330 and A340

[26] SkyBook is an Operator's paper-free information, which securely handles and presents all applications and documents relevant to the operation of a flight for every pilot. Additionally recurrent training and daily communication can be handled in a fast, professional and secure way.

aircraft. Unreliable airspeed indication and dual ADR fault subjects were also included in the Operator's *FCTM* (see also Paragraph 1.18.1).

1.18 Additional Information

1.18.1 The FCTM

1.18.1.1 Unreliable Airspeed Indication

Based on the Operator's current *FCTM*, the description of unreliable airspeed indication is described as:

"The ADRs detect most of the failures affecting the airspeed or altitude indications. These failures lead to:

- Lose the associated speed or altitude indications in the cockpit
- Trigger the associated ECAM alerts

However, there may be cases where an airspeed and/or altitude output is erroneous and the ADRs do not detect it as erroneous. In such a case, no ECAM alert is triggered and the cockpit indications may appear to be normal whereas they are actually false. Flight crews must have in mind the typical symptoms associated with such cases in order to detect this situation early and apply the "UNRELIABLE SPEED INDIC/ADR CHECK PROC" QRH procedure.

Main Reasons for Erroneous Airspeed Indication/Altitude Data

The most probable reason for erroneous airspeed indication and/or altitude information is an obstruction of the pitot and/or static probes. Depending on how the probe(s) is obstructed, the effects on cockpit indications differ.

It is highly unlikely that all of the aircraft probes will be obstructed at the same time, to the same degree and in the same way. Therefore, the first effect of erroneous airspeed indication/altitude data noticeable in the cockpit will most probably be a discrepancy between the various indications (CAPT PFD, F/O PFD and STBY instruments).

Consequences of Obstructed Pitot Tubes or Static Probes

All the aircraft systems which use anemometric data, have built-in fault accommodation logics. The fault accommodation logics rely on a voting principle: When the data provided by one source diverges from the average value, the systems automatically reject this source and continue to operate normally using the remaining two sources. The flight control system and the flight guidance system both use this voting principle.

Normal Situation

Each FCPC receives speed information from the three ADRs and compares the three values. The FCPCs do not use pressure altitude.

Each FE (Flight Envelope) computer receives speed and pressure altitude information from the three ADRs and compares the three values.

One ADR Output is Erroneous and the Two Remaining Outputs are Correct

The FCPCs and the FEs eliminate the erroneous ADR. On A340-500/600s, if one ADR deviates, and if this ADR is used to display the speed information on either the CAPT or F/O PFD, a NAV IAS DISCREPANCY ECAM caution is triggered. Furthermore, the autoland capability is downgraded to CAT 3 SINGLE.

Two ADR Outputs are Erroneous, but Different, and the Remaining ADR is Correct, or if All Three ADRs are Erroneous, but Different

Both the AP and A/THR disconnect. If the discrepancy lasts for more than 10 s, the FCPCs trigger the NAV ADR DISAGREE“ ECAM caution.

The flight controls revert to ALTN 2 law. The high speed and low speed protections are lost.

On both PFDs:

- The SPD LIM flag appears
- No VLS and no VSW is displayed

This situation is latched for the remainder of the flight, until the FCPCs are reset on ground, without any hydraulic pressure.

However, if the anomaly is only transient, the AP and the A/THR can be re-engaged when the discrepancy disappears.

In-Service Experience of High Altitude Pitot Obstructions

Analysis of the in-service events shows that:

- At high altitude, typically above FL 250, the cases of unreliable speed situation are mostly a temporary phenomenon: They are usually due to contamination of the pitot probes, by water or ice, in particular meteorological conditions. In-service experience shows that such contamination typically disappears after few minutes, allowing a recovery of normal speed indications."

1.18.1.2 Operational Recommendations for Weather Detection

At the time of the Incident, the operational recommendations for weather detection which were provided in the Operator’s *FCTM*, are described below:

“Effective tilt and ND range management is a key element for weather radar operation:

- First, the flight crew has to choose the ND range, depending on FL and detection requirement (long distance/short distance).
- Then, the flight crew adjusts tilt to maintain ground return on top of ND (except during takeoff, climb and approach).

Flight Phase	Detection and Monitoring	Comments
TAXI	Clear on parking area, set ND to lowest range. Tilt down then up. Check appearance/disappearance of ground returns.	Antenna tilt check (away from people)

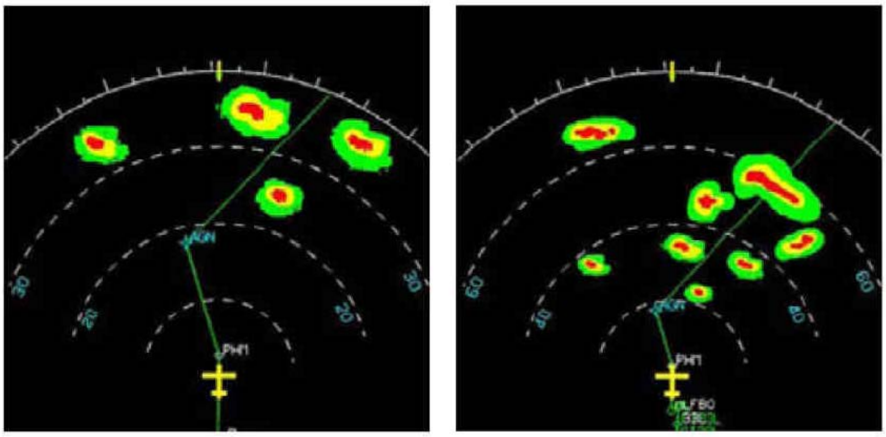
TAKEOFF	If weather activity is suspected: slowly scan up to detect weather (Max 15 °up), otherwise: set tilt to 4 ° up	Enables to scan along the departure path
CLIMB	Adjust the ND range as required and decrease the tilt angle as the aircraft climbs	Avoids over scanning of weather
LEVEL FLIGHT/CRUISE	Depending on FL and detection requirement, adjust ND range. Maintain the ground return on the top of the ND Regularly scan the weather vertically by modifying the tilt Once the scan is done, adjust the ground return back on the top of the ND.	In cruise, for efficient weather awareness, the following ranges can be selected: - 160 nm on the PNF ND - 80 nm on the PF ND Shorter ranges can be used to track/avoid closing weather.
DESCENT	During descent, tilt upward to maintain the ground return on the top of the ND.	-
APPROACH	Tilt 4° up	Avoids ground return

Note: It is difficult to differentiate between weather returns and ground returns: A change in TILT causes the shape and color of ground returns to change rapidly. These ground returns eventually disappear. This is not the case for weather returns.

RANGE MANAGEMENT

The flight crew should monitor the weather at long range, as well as at shorter ranges, in order to be able to efficiently plan course changes, and to avoid the blind alley effect.

Blind Alley Effect



ND Range = 40 NM   ND Range = 80 NM

TURBULENCE DETECTION

- The turbulence display is most effective when the ND is set on 40 nm (corresponds to the maximum turbulence detection range).
- Closely spaced (or thin lines between) color gradations are usually associated with severe turbulence."

1.18.1.3 Weather Data Analysis

At the time of the Incident, the weather data analysis was provided in the Operator's *FCTM*, as described below.

"Evaluation of Cell Vertical Expansion

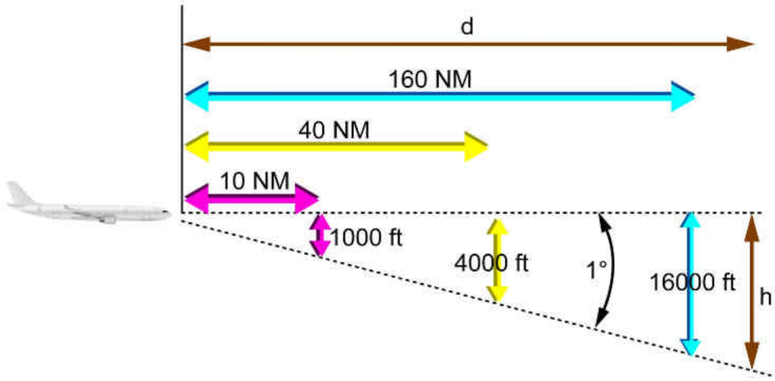
When flying towards a cell, the flight crew can get an estimate of the vertical expansion of the cloud above/below the aircraft altitude with the following formula:

h(ft) ≈ d(NM) x Tilt(^{0}) x 100

Tilt represents the tilt selected so that the cell image disappears from the display.

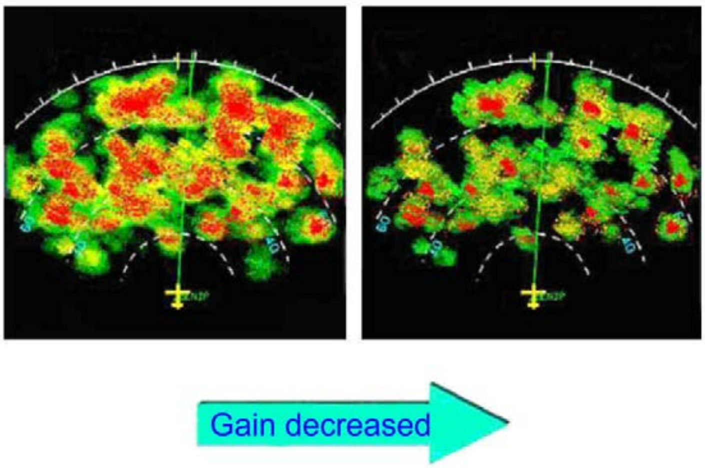
For example, an echo disappearing at 40 nm with 1 ° tilt down has a top located 4 000 ft below the aircraft altitude.

The flight crew can increase the gain to make the frozen (less reflective) storms top more visible.



Saturated Weather Return

To assess the general weather conditions the flight crew may use manual gain. Manual gain is particularly useful, when operating in heavy rain, if the radar picture is saturated. In this case, reduced gain will help the flight crew to identify the areas of heaviest rainfall, that are usually associated with active storm cells. To recover optimum radar sensitivity once the cell assessment is done, the flight crew must reset the GAIN knob to AUTO/CAL.



"

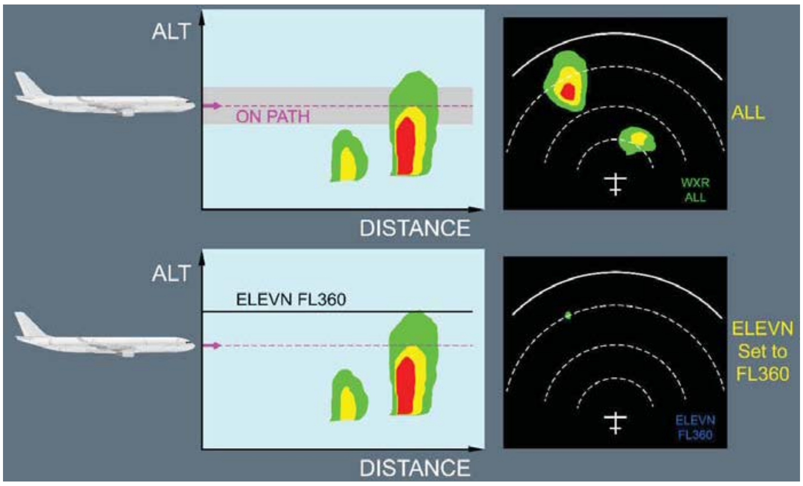
In the most recent revision of the Operator's *FCTM* dated on 03 March 15, there is one additional subject regarding 'Elevation of Cell Vertical Expansion' added to the weather data analysis section, as shown below.

"Elevation of Cell Vertical Expansion

The flight crew can assess the top of cells without any calculation by using the manual elevation mode. To select the manual elevation display mode, the flight crew sets the Display Mode selector to ELEVN on the weather radar control panel. Then, the crew turns the ELEVN knob of the weather radar control panel until the cell disappears, and reads the corresponding altitude (or FL depending on barometric setting) on the ND.

The flight crew can increase the gain to make the frozen (less reflective) storms top more visible.

Example of Cell Vertical Expansion Evaluation



"

1.18.2 UNRELIABLE SPEED INDIC/ADR Check PROC – QRH Procedure

According to the *FCTM*:

"The "UNRELIABLE SPEED INDIC/ADR CHECK PROC" procedure has two objectives:

- To identify and isolate the affected ADR(s),
- If not successful, to provide guidelines to fly the aircraft until landing.

It includes the following steps:

1. Memory items (if necessary),
2. Troubleshooting and fault isolation,
3. Flight using pitch/thrust references or the Back-Up Speed Scale (BUSS, below FL 250), if troubleshooting has not been successful in isolating the faulty ADRs.

When to Apply This Procedure

The flight crew should consider applying the relevant "UNRELIABLE SPEED INDIC/ADR CHECK PROC" procedure when:

- The "UNREL SPD PROC… APPLY" action line is displayed on ECAM, for example due to the NAV ADR DISAGREE or A.ICE CAPT (F/O) (STBY) PITOT HEAT alerts, or

- The flight crew suspects an erroneous indication, without any ECAM alert.

The flight crew can suspect an erroneous speed/altitude indication, in the following cases:

1. A speed discrepancy (between ADR1, 2, 3 and standby indications),
2. Fluctuating or unexpected changes of the indicated airspeed or altitude,
3. Abnormal correlation between the basic flight parameters (pitch, thrust, airspeed, altitude and vertical speed indications). For example:
   - The altitude does not increase, whereas there is an important nose-up pitch and high thrust,
   - The IAS increases, whereas there is an important nose-up pitch,
   - The IAS decreases, whereas there is an important nose-down pitch,
   - The IAS decreases, whereas there is a nose-down pitch and the aircraft is descending.
4. An abnormal behavior of the AP/FD and/or the A/THR,
5. The STALL warning triggers, the OVERSPEED warning triggers, or the FLAP RELIEF message on the E/WD appears, and this is in contradiction to the indicated airspeeds. In this case:
   - Rely on the STALL warning. Erroneous airspeed data does not affect the STALL warning, because the STALL warning is based on Angle Of Attack (AOA) data,
   - Depending on the situation, the OVERSPEED warning may be false or justified. When the OVERSPEED VFE warning triggers, the appearance of aircraft buffet is a symptom that the airspeed is indeed excessive.
6. The barometric altitude is not consistent with the radio altitude (when the RA is displayed),
7. The aerodynamic noise reduces whereas the indicated airspeed increases, or vice versa,
8. On approach, it is not possible to extend the landing gear using the normal landing gear system.

Note:

1. Crew coordination is important. The PNF should confirm any discrepancy:

- *Between the standby airspeed indication and the speed indication on his/her PFD,*
- *Between his/her PFD and the Pilot Flying's PFD.*

2. Because the barometric altitude may be erroneous, the aircraft may not be able to accurately maintain level flight. In addition, the ATC transponder may transmit an incorrect altitude to ATC or to other aircraft, which can lead to confusion. Therefore, the flight crew should advise ATC of the situation without delay."

1.18.3 QRH Computer Reset Table

This table below lists the computers that had been reset in an attempt to re-engage the autopilot.

Most of the computers' reset capability is provided on the overhead RESET panel.

"To reset a computer:

- Set the related normal cockpit control OFF, or pull the corresponding reset pb,
- Wait 3 s, if a normal cockpit control is used (unless a different time is indicated), or 1 s if a reset pb is used,
- Set the related normal cockpit control ON, or push the corresponding reset pb,
- Wait 3 s for the end of the reset.

WARNING	Do not reset more than one computer at a time, unless instructed to do so.

The following table lists the various computers for which manual reset capability is provided:

- On the overhead RESET panels,
- On the system control panel.

For each computer reset, the table lists the effects and/or precautions where applicable ("NIL" indicates no additional effects and/or precautions apply).

- A computer reset has to be attempted when:
  - recommended by an ECAM procedure or
  - recommended by a paper procedure.
- In all other circumstances, where a failure is suspected or detected, there is no specific recommendation as to whether a reset should be performed or not, except those where a reset is specifically forbidden.

Manual reset on ground triggers a complete power up test.

The number of reset attempts is not limited.

ATA	EQUIPMENT	REMARKS
22	FMGEC	FMGEC reset results in onside AP disconnection (if engaged). It is recommended to use the FMGEC reset pb ,

		rather than the FM reset pb.
27	FCPC and FCSC *	- FCPC/FCSC may be reset, except in the following case: • The DC BUS 2 FAULT caution is present. *Note:* *Do not attempt a reset because this would result in a loss of related FCPC/FCSC* - If a reset is performed on ground, it must be followed by a flight controls' check WARNING Do not reset more than one computer at a time. *Note:* *When a PRIM reset is performed on ground, the crew must check the pitch trim position.*
	FCDC	NIL
31	SDAC	NIL

"

1.18.4 Unreliable Airspeed Indication Study

Aviation accident literature contains unreliable airspeed indication events involving Airbus A330/A340 aircraft. The most notable accident involved an Air France A330 aircraft operating flight No. AF447. As of 3 November 2009, the aircraft manufacturer had identified 36 events affecting Airbus A330/A340 type aircraft that were attributable to the blocking of at least two pitot probes with ice, as mentioned in the interim report no. 2 of the AF 447 accident investigation. In two of the thirty six events, the aircraft were fitted with Goodrich 0851HL pitot probes.

In the Final Report of the investigation into the AF447 accident, it is stated that the BEA had studied thirteen unreliable indicated airspeed events involving the temporary loss of airspeed reading, or other anomalies, for which it had access to crew reports, recorded parameters and the PFR.

Some of the significant findings of the study were:

- The flight levels at which the aircraft were flying, were between FL340 and FL390.
- The static temperature was less than -40°C in twelve cases. In ten cases, it exceeded the temperature in standard atmosphere by between 0 °C to 6°C; in three other cases, it was higher than temperature in standard atmosphere by more than 10°C, STD+10^{0}C.
- The recordings of the total or static temperatures revealed increases of 10 °C to 20 °C during the event.
- Turbulence was always recorded and reported. The levels felt by the crews varied from light to strong. The range of vertical acceleration values recorded varied from [0.75/1.2g] to [0.2/1.9g].

- In twelve cases, the flight control law changed to Alternate Law until the end of the flight. In one case, this transition was temporary.
- The variations in altitude were contained within about 1,000 ft. There were five cases where the aircraft was deliberately descended, including one descent of approximately 3,500 ft. These descents followed stall warnings.

In the Incident that is the subject of this Report, the Aircraft had entered similar environmental conditions to the thirteen events mentioned above (see paragraph 1.11.1.1).

1.18.5 Pitot Probe Design, Specification and Certification

1.18.5.1 At the Time of the Incident

The pitot probes installed on the Aircraft complied with the European *Joint Aviation Requirement (JAR)*, Section 25.1419 and Appendix C which contained certification specifications for validating the ice protection system on the Airbus A340-600 in super-cooled water icing conditions. The specifications state that the aircraft must be able to safely operate in continuous maximum icing[27] conditions and intermittent maximum icing[28] conditions.

The Aircraft manufacturer requirements for the ice protection system of the Aircraft exceeded the envelope specified by the JAR 25 certification requirements.

The JAR specification and the manufacturer requirements for the Aircraft ice protection system are shown in Figure 18, including the altitude and static ambient temperature (SAT) conditions that applied to the Incident. During the Incident, the Aircraft encountered conditions that were outside the JAR specification and the Aircraft manufacturer requirements.

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[27] Continuous maximum icing is the maximum continuous intensity of atmospheric icing conditions, which is defined by the variables of the cloud liquid water content, the mean effective diameter of the cloud droplets, the ambient air temperature, and the interrelationship of these three variables. The continuous maximum envelope corresponding to an average cloud 17.4 nautical miles long, with low water concentrations, rising up to 22,000 feet and with a temperature as low as - 30°C.

[28] Intermittent maximum icing is the intermittent maximum intensity of atmospheric icing conditions which is defined by the variables of the cloud liquid water content, the mean effective diameter of the cloud droplets, the ambient air temperature, and the interrelationship of these three variables. The intermittent maximum envelope corresponding to an average cloud 2.6 nautical miles long, with high water concentrations, with values up to 30,000 ft and - 40 °C.

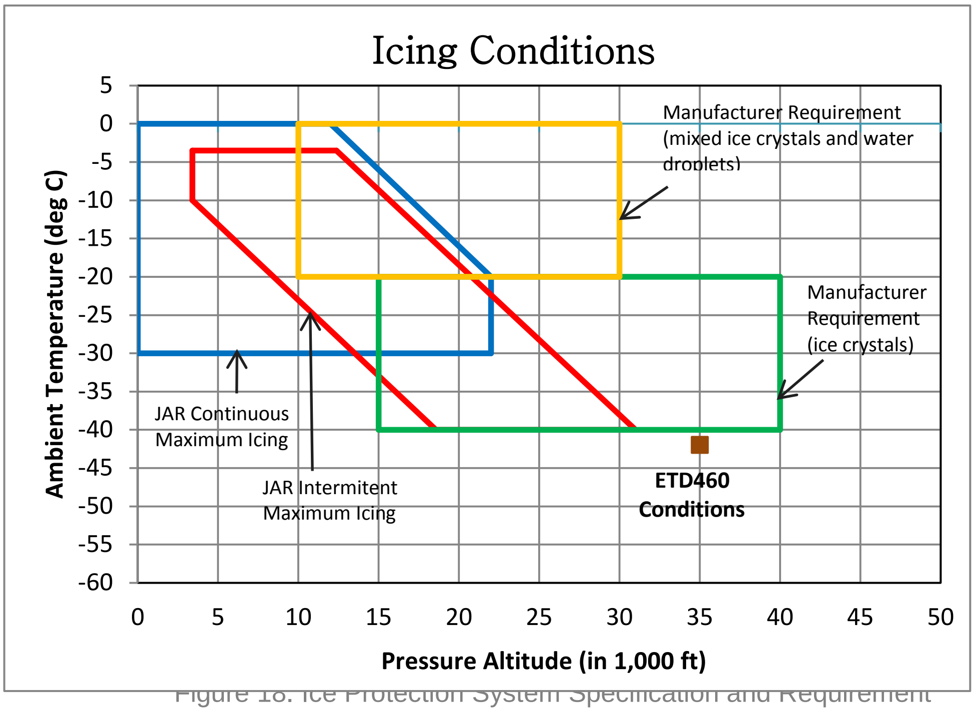

Figure 18: Ice Protection System Specification and Requirement

As stated in paragraph 4.1.2 of the AF447 Final Report:

"The examination of reported unreliable airspeed events in cruise has shown that the majority of them occurred outside of the envelope defined in Appendix C to JAR 25. In fact, the certification criteria are not representative of the conditions that are really encountered at high altitude for example with regard to temperatures. In addition, it appears that some elements, such as the size of the ice crystals within cloud masses, are little known and that it is consequently difficult to evaluate the effect that they may have on some equipment, in particular the pitot probes. In this context, the tests aimed at the validation of this equipment do not appear to be well-adapted to flights at high altitude. Consequently, the BEA recommends that EASA to undertake studies to determine with appropriate precision the composition of cloud masses at high altitude; and in coordination with the other regulatory authorities, based on the results obtained, to modify the certification criteria."

EASA has responded the two BEA recommendations as given below.

"Recommendation FRAN-2009-019 received on 06/01/2010

Subject:	Accident to Airbus A330-203, registration F-GZCP, on 01/06/2009, enroute between Rio de Janeiro and Paris
Safety Recommendation:	The BEA recommends that EASA undertake studies to determine with appropriate precision the composition of cloud masses at high altitude.
Response:	EASA is involved in coordinated research activities which have been triggered and launched. The objective is: - to determine with appropriate precision the composition of cloud masses at high altitude, - to have a characterization of high altitude atmosphere, and

	- to investigate the engineering and scientific issues related to characteristics of convective clouds. EASA launched the study High IWC (High Ice Water Content), which will contribute to the international project HAIC (High Altitude Ice Crystals).
Status:	Closed - Agreement

"

"Reply to Safety Recommendation FRAN-2009-020 received on 06/01/2010

Safety Recommendation:	The BEA recommends that EASA in coordination with the other regulatory authorities, based on the results obtained, modify the certification criteria.
Response:	The Agency will soon amend CS-25 and CS-E with the introduction of new environmental icing conditions for ice crystals and mixed phased (rulemaking tasks RMT.0058 and RMT.0179). A new Appendix P to CS-25 will be introduced. These conditions were recommended by the Ice Protection Harmonization Working Group (IPHWG) based on the best available scientific knowledge from the different domains of expertise. The Agency funded a study EASA.2011.OP.28 entitled "HighIWC – Ice Water Content of clouds at High Altitude" which delivered its final report in December 2012. Part of this study, an evaluation of the proposed Appendix P environment was conducted against the most recent available information from research literatures, large aeroplane manufacturers and research institute flight tests, and known in-service events. The proposed Appendix P was specifically designed for engines testing. However, it has been confirmed by the above evaluation that for flight instrument probes, in particular Pitot probes, additional test conditions should be prescribed to reflect the fact that Pitot probes are more sensitive to ice crystals peak concentration values. A similar recommendation was made by EUROCAE WG-89 in charge of preparing a new standard applicable to Pitot probes ETSO/TSO. Therefore the Agency included in its proposal for amending CS-25 some additional specifications applicable to flight instrument probes, taking into account the recommendations received. It is considered that the future amendment will provide an adequate level of protection covering known in-service occurrences. Furthermore, a generic Special Condition (SC) is used by the Agency for all CS-25 aeroplane applications made after January 2010. The technical content of the SC is consistent with the proposed amendment of SC-25 for flight instrument probes ice protection. Nevertheless, to perform a statistical approach of the analysis of the new Appendix P in terms of concentrations, and to better understand the microphysical properties and structure of deep convective cloud systems, additional results and measurements of the atmosphere are needed. These results should be provided as part of an international flight test campaign that is being prepared. The Agency will continue to be deeply involved in this activity. A

	second EASA study is being prepared for 2013, which will contribute to the European HAIC (High Altitude Ice Crystals) project and the International HIWC (High Ice Water Content) project, dedicated to the flight test campaign preparation (planned in 2014). After this campaign, a data analysis phase will be conducted and, depending on the conclusions, this may lead to a future amendment of EASA Certification Specifications.
Status:	Closed - Agreement

"

1.18.5.2 Progress on implementation of BEA Recommendations

The progress on the implementation of the EASA responses to the two BEA recommendations, at the time of the Investigation, is as described below.

A new certification specification for environmental icing conditions for ice crystals and mixed phase was introduced by publishing CS-25/Amendment 16 and CS-E/Amendment 4 of 12 March 2015, issued by EASA.

A new standard applicable to pitot probes, which is a revision of ETSO C16 (pitot tubes), has been developed by EUROCAE-SAE, and this will be approved and released in 2015, then the ETSO revision will follow at the next regular CS-ETSO update.

The CS-25 amendment provides new icing test conditions for all flight probes, and they will be consistent with the new ETSO standards, such that the delay of the ETSO revision is not a source of concern.

At present, EASA is working with Airbus on the certification of new pitot probes for Airbus aircraft. The new probes will be compliant with a Special Condition mandating environmental conditions equivalent to the qualification aspects in icing conditions of the new requirements of CS-25 Amendment 16, which was published on 12 March 2015. EASA received the certification application for the new probes at the end of 2014. It is expected that the certification project duration will be approximately one year.

EASA has not yet discussed with Airbus, neither the forward fit, nor the retrofit policy. However, EASA expects that when the probes are certified, then they will be at least installed on forward fit aircraft.

Referring to BEA recommendation (EASA responds to BEA FARN-2009-019), EASA is involved in the High Altitude Ice Crystals - High Ice Water Content project (HAIC-HIWC) international research project (EASA High IWC project). After the first flight test campaign of 2014, which was based in Darwin, Australia, a second campaign is scheduled for spring 2015.

The Aircraft Manufacturer is involved in the working group which defines new certification criteria for the pitot probes. New pitot probes are being designed by Airbus and its providers, and will comply with the new regulation.

Airbus has already launched the design of a new pitot probe with the involved manufactures. This new pitot probe will be in compliance with the new regulation and will be made available for production aircraft as soon as it is certified.

1.18.5.3 CS-25 / Amendment 16

Two new appendices are introduced to CS-25 Amendment 16: Appendix O describes 'Supercooled Large Drop (SLD) Icing Conditions'; and Appendix P defines 'Mixed phase and ice crystal icing envelope (Deep convective clouds)'.

A detailed description of Appendix P to the new CS-25 Amendment 16 is given in Appendix 3 of this report.

A summary of the new CS-25 for aircraft ice protection system is shown in Figure 19. When the altitude and static ambient temperature (SAT) of the Incident Aircraft are included, the condition will be within the envelope, which was not the case at the time of the Incident.

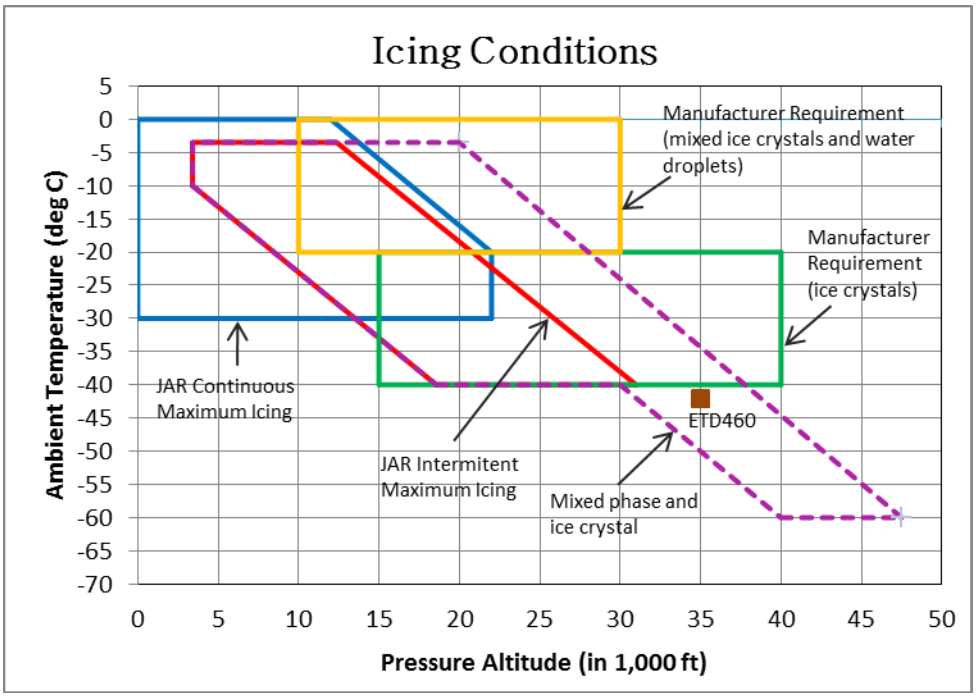

Figure 19. Ice Protection System according to the New CS-25 Amendment 16

1.18.6 The FCOM

The abnormal and emergency procedure for NAV ADR DISAGREE given in the *FCOM*, as shown in Figure 20, did not reflect the fact that the autopilot could not be re-engaged for the remainder of the flight, if the FCPCs have definitely rejected the three ADRs. In addition, the fact that the automatic landing capability then reduces to Category (CAT) 1 was not stated in the FCOM.

ETIHAD A330/A340 FLIGHT CREW OPERATING MANUAL	PROCEDURES ABNORMAL AND EMERGENCY PROCEDURES NAVIGATION

NAV ADR DISAGREE

Applicable to: MSN 0748, 0757, 0761, 0783, 0829, 0837, 0870, 0929, 0933, 1030, 1040

Ident.: PRO-ABN-34-P-00011469.0001001 / 09 MAR 11

L2 This caution is triggered by the PRIMs, when they use only 2 ADRs, and when these 2 ADRs disagree. This may occur, when:
- One ADR has already been selected OFF by the pilot, or
- One ADR has been eliminated by the PRIM, without any caution, because it deviated from the others.

L1 AIR SPD...X CHECK

L2 *Check airspeed information on both PFDs, and on the standby airspeed indicator.*

L1 ■ **IF NO SPD DISAGREE:**
AOA DISCREPANCY

■ **IF SPD DISAGREE:**
ADR CHECK PROC...APPLY

L2 *Refer to PRO-ABN-34 UNRELIABLE SPEED INDICATION/ADR CHECK PROC - GENERAL .*

L12

ASSOCIATED PROCEDURES

F/CTL ALTN LAW
(PROT LOST)

Note: *Following an ADR DISAGREE, detected by the PRIMs, alternate law is latched. Resetting the PRIMs, by using the pushbutton, does not allow normal law recovery.*

Refer to PRO-ABN-27-H F/CTL ALTN LAW (PROT LOST).

L1 MAX SPEED...305/.82

Continued on the following page

NAV ADR DISAGREE (Cont'd)

Ident.: PRO-ABN-34-P-00011470.0007001 / 11 MAY 12

L12

STATUS

MAX SPEED...305/.82

APPR PROC:

FOR LDG...USE FLAP 3

This line is replaced by "FOR LDG : USE FLAP 3" when CONF 3 is selected, as a reminder.

LDG DIST PROC...APPLY

CAT 3 SINGLE ONLY

RISK OF UNDUE STALL WARN

Undue stall warnings may mainly occur, in case of an AOA discrepancy.

RUD WITH CARE ABV 160 KT

The rudder travel limit value is frozen at the moment when the failure occurs. Therefore, to prevent damage to the aircraft structure, use the rudder with care, when the speed is above 160 kt. At slats' extension, full rudder travel authority is recovered.

INOP SYS

RUD TRV LIM
CAT 3 DUAL

Figure 20. Abnormal and Emergency Procedure for NAV ADR DISAGREE

As a safety action, the manufacturer updated the related procedures by adding a note regarding the definitive loss of the autopilot when a NAV ADR DISAGREE is detected by the FCPCs, and the relevant inoperative systems. The revision was dated on 27 November 2013 and provided to the Operator, as shown in Figure 21.

الاتحاد ETIHAD A330/A340 FLIGHT CREW OPERATING MANUAL	PROCEDURES ABNORMAL AND EMERGENCY PROCEDURES NAVIGATION

NAV ADR DISAGREE

Applicable to: MSN 0748, 0757-0783, 0829, 0837, 0870, 0929-0933, 1030, 1040

Ident.: PRO-ABN-34-P-00011469.0004001 / 26 NOV 13

L2 This caution is triggered by the PRIMs, when they use only 2 ADRs, and when these 2 ADRs disagree. This may occur, when:
- One ADR has already been selected OFF by the pilot, or
- One ADR has been eliminated by the PRIM, without any caution, because it deviated from the others.

L1 AIR SPD....................X CHECK

L2 *Check airspeed information on both PFDs, and on the standby airspeed indicator.*

L1 ■ **IF NO SPD DISAGREE:**

AOA DISCREPANCY

■ **IF SPD DISAGREE:**

ADR CHECK PROC....................APPLY

L2 *Refer to PRO-ABN-34 UNRELIABLE SPEED INDICATION/ADR CHECK PROC - GENERAL* .

L12

ASSOCIATED PROCEDURES

AUTO FLT AP OFF

Note: *Following an ADR DISAGREE, detected by the PRIMs, AP1 and AP2 are definitively lost. The automatic landing capability downgrades to CAT 1. FD1 and FD2 disengage. FD1 and FD2 may re-engage if 2 ADR become consistent.*

Refer to PRO-ABN-22 AUTO FLT AP OFF

F/CTL ALTN LAW
(PROT LOST)

Note: *Following an ADR DISAGREE, detected by the PRIMs, alternate law is latched. Resetting the PRIMs, by using the pushbutton, does not allow normal law recovery.*

Refer to PRO-ABN-27 F/CTL ALTN LAW (PROT LOST).

L1 MAX SPEED....................305/.82
RUD WITH CARE ABV 160KT

Continued on the following page

ETD A330/A340 FLEET — PRO-ABN-34 P 18/72
FCOM — H → — 27 NOV 13

ETIHAD A330/A340 FLIGHT CREW OPERATING MANUAL	PROCEDURES ABNORMAL AND EMERGENCY PROCEDURES NAVIGATION

NAV ADR DISAGREE (Cont'd)

Ident.: PRO-ABN-34-P-00011470.0008001 / 26 NOV 13

L12

STATUS

MAX SPEED.......................................305/.82
RUD WITH CARE ABV 160KT
See (1)

APPR PROC:

—FOR LDG.......................................USE FLAP 3
This line is replaced by "FOR LDG : USE FLAP 3" when CONF 3 is selected, as a reminder.

—LDG DIST PROC.......................................APPLY
ALTN LAW: PROT LOST
RISK OF UNDUE STALL WARN
Undue stall warnings may mainly occur, in case of an AOA discrepancy.

INOP SYS

F/CTL PROT
RUD TRV LIM
AP 1+2
CAT 2

(1) *The rudder travel limit value is frozen at the moment when the failure occurs. Therefore, to prevent damage to the aircraft structure, use the rudder with care, when the speed is above 160 kt. At slats extension, full rudder travel authority is recovered.*

NAV ALTI DISCREPANCY

Ident.: PRO-ABN-34-00011434.0001001 / 18 AUG 10
Applicable to: ALL

ALT.......................................X CHECK
L2 *Crosscheck with the standby altimeter.*
L1 AIR DATA SWTG.......................................AS RQRD
L2 *Select ADR 3 to the faulty side.*

Figure 21. Revision of Abnormal and Emergency Procedure for NAV ADR DISAGREE After the Incident

1.18.7 Manufacturer Documentation

1.18.7.1 Manufacturer *Flight Operations Briefing Notes – Adverse Weather Operations/ Optimum Use of of the Weather Radar*

The manufacturer published a Flight Operations Briefing Note for Adverse Weather Operations, specifically referring to the optimum use of the weather radar.

The aim of this Flight Operations Briefing Note is to provide additional information about weather radar capabilities and limitations, in order to improve overall understanding of the system by pilots, and to help in preventing the occurrence of incidents and accidents.

1.18.7.2 Manufacturer Document '*Getting to Grips with Cold Weather Operations*'

The manufacturer published a document '*Getting to Grips with Cold Weather Operations*'.

The purpose of this document is to provide operators with an understanding of Airbus aircraft operations in cold weather conditions, and address such aspects as aircraft contamination, performance on contaminated runways, fuel freezing limitations, and altimeter corrections.

1.19 Useful or Effective Investigation Techniques

No new investigation techniques were used during this investigation.

2. Analysis

2.1 General

The Investigation team collected data from various sources for the purpose of determining the incident causes and contributing factors of the Incident.

This 'Analysis' discusses the issues of the use of weather radar, airspeed fluctuation, N1 Vibration, flight crew performance, and the design requirement of the pitot probes.

This Section of the Report explains the contribution of every aspect of the investigation to the Incident. The 'Analysis' also contains safety issues that may not be contributory to the Incident but are significant in adversely affecting safety.

2.2 Weather Radar

Before the Incident occurred, the Aircraft was cruising at FL350 in instrument meteorological conditions (IMC), within Cirrocumulus cloud of about 5,000 to 7,000 ft thickness and in light turbulence. The weather radar was showing almost no, or very few, green returns.

The fixed time prognostic chart of the Indian Ocean, valid for 00:00 UTC, 3 February 2013, from FL250 to FL450, indicated an area of isolated embedded cumulonimbus clouds up to FL450 in the area where the Incident events commenced.

The turbulence started to increase slightly, and the radar returns became stronger from mainly black to 80% green, then from green to 80% yellow. Suddenly, the radar returns showed 2-3 millimeters of solid red around the Aircraft symbol.

The weather radar was manually set to GAIN: Auto and Radar Tilt to -0.8. Usually, setting the antenna tilt to about one degree will allow the flight crew to observe weather ahead and slightly below the aircraft.

Since the weather radar was not equipped with an auto-tilt function, finding the optimum tilt setting manually, together with an optimum selection for the ND range, would require optimization in observing the most reflective part of the cloud and reducing ground clutter returns. This optimum tilt setting should be established before encountering the adverse weather, in order to have sufficient time for avoidance action.

At the high altitude where the Aircraft was operating, the weather radar was displaying the cell which had ice particles, but the reflection of the ice particles was weak. The incorrect high tilt setting caused the radar to scan only the upper (less reflective) part of the cell. The antenna tilt setting was, most probably, so high that it could not depict the weather conditions ahead of the Aircraft accurately.

Therefore, the Investigation believes that the antenna tilt and the ND range were not effectively managed by the flight crew to ensure sufficient monitoring of the weather conditions ahead. Also, the Investigation believes that the GAIN knob was not used in manual setting to analyze the weather ahead in-depth.

As a result, the strength of the cell was underestimated, which most probably, reduced the awareness and ability of the crew taking proactive avoidance action, before encountering the area of isolated embedded Cumulonimbus clouds.

During the diversion to Singapore, the Aircraft descended to FL290 in order to vacate Reduced Vertical Separation Minimum (RVSM) airspace and to maintain visual meteorological conditions (VMC) since the flight crew assumed that the weather radar was unserviceable. Their assumption was negated when the Cumulonimbus clouds on approach to Singapore International Airport were displayed normally.

According to radar manufacturers, observations on the weather radar performance were recorded by many operators, and the manufacturer conclusion to these observations was that poor tilt management is the leading cause of poor radar performance.

The capability of the weather radar is limited to detecting wet particles such as rain, wet hail and wet snow. The radar cannot detect dry hail, ice crystals, or dry snow which is commonly found at high altitudes.

Adequate skills are required in order to use the weather radar efficiently as a tool for detecting and avoiding adverse weather and turbulence. Therefore, training and mastering the use of radar, especially the tilting function, is necessary to minimize errors.

Training to use the system correctly should include: detection capability of the weather radar; interpretation of the weather based on the shape, the colour, and the size of returns; effective management of the antenna tilt along with an appropriate ND range selection; when to use the GAIN in AUTO and Manual to evaluate initially and to analyze the weather; how to detect turbulence from the weather radar using the TURB (Turbulence) function; where to focus on the most reflective precipitation including the cumulonimbus structures; and the use of weather radar in conjunction with the weather report and weather forecast.

The Manufacturer had published *Flight Operations Briefing Notes for Adverse Weather Operations*, specifically about the *optimum use of the weather radar*, and the document *Getting to Grips with Cold Weather Operations*, therefore the Investigation recommends the Operator to add the existing initial and refresher type training syllabus, by including material as given in these briefing notes and document, and other adequate material on the manual tilt selection of the weather radar antenna, in order to maximize the weather survey and detection functions.

2.3 Airspeed Indication Fluctuations

There were three occasions of airspeed indication fluctuations found during the Incident.

First fluctuation/unreliable airspeed

The first fluctuation/unreliable airspeed occurred on CAS1 and CAS3 and lasted for about 16 seconds, causing disconnection of the FDs, triggering of master warnings, disconnection of AP1, which triggered the message “AUTO FLT AP OFF” on the ECAM, and loss of A/THR which triggered the message “AUTO FLT A/THR OFF”.

Based on the FCPC-ADR monitoring (flight control monitoring), the rejection of all three ADRs, consequently resulted in a flight control law transition from Normal Law to Alternate Law, which triggered the message “F/CTL ALTN LAW” on the ECAM.

During the 16 seconds of the first fluctuation of CAS1 and CAS3 values, there was always one ADR output (e.g. CAS1 or CAS3) which deviated excessively.

When the fluctuating airspeed indications returned within tolerance, all ADRs again became valid and were used by the FMGEC and FCPC. In fact, the rejection of ADR1 by FCPC was temporary since CAS1 was out of tolerance for less than 10 seconds. Consequently, the flight control law returned to Normal Law after the Alternate Law reversion. At that time, the AP could have been re-engaged. This was not attempted by the flight crew. The A/THR was re-engaged thereafter.

Second fluctuation/unreliable airspeed Indication

The second fluctuation/unreliable airspeed indication occurred on CAS1 and lasted for about one second. After that, the airspeed indication returned to normal with no effect on the FDs. Both FDs remained engaged as two CAS values (CAS2 and CAS3) out of the three available remained steady during the temporary ADR1 rejection.

Third fluctuation/unreliable airspeed Indication

The third fluctuation/unreliable airspeed indication occurred on CAS1 and CAS3. At the beginning of the third fluctuation, the CAS1 value reduced and was out of tolerance for more than 10 seconds, and the rejection of the ADR1 by the FCPC was latched through the monitoring of ADR airspeeds comparison. Then the CAS3 value reduced becoming out of tolerance until the FCPC rejected the remaining ADRs, 2 and 3.

The triggering of the message “NAV ADR DISAGREE” on the ECAM meant that the rejection of all three ADRs was latched by the FCPC and the flight control reverted to Alternate Law, and it remained until the end of the flight, which made autopilot reengagement impossible.

The fluctuating or unreliable airspeed indications occurred on CAS1 and CAS3, while the CAS2 value was indicating normal steady indicated airspeed. This showed that, most probably, only the Aircraft left side pitot probes were temporarily obstructed by ice crystals.

During the period of the airspeed indication fluctuations, there were associated changes in the values of altitude and SAT. The changes were consistent with the fluctuations in the indicated airspeed, but were inconsistent with the physical flight which gave a clue that the displayed airspeeds were false. There were no anomalies of the angle of attack data, nor triggering of the stall warning system during the Incident.

This unreliable airspeed Incident was a temporary phenomenon due to contamination of the left side pitot probes, and disappeared after a short time. Following that, normal airspeed indications returned. Based on the systems descriptions, the related logics of the FMGES and FCS, these systems functioned as designed during the event.

The Investigation believes that the normal airspeed, altitude, AOA, and temperature readings during the ferry flight of the Aircraft to its base also proved that the airspeed fluctuations during the Incident flight were caused by temporary blockages of the left pitot probes, and no deficiencies in the systems related to airspeed, altitude, AOA, or temperature were found.

There was no evidence that the blockage of the left pitot probes was due to a malfunction in the probe heating systems, since the PFR data did not show any failure of the probe heat computers.

2.4 No. 2 Engine N1 Vibration

The N1 vibration on No. 2 engine increased from 0.3 units to a maximum of 7.1 units after the fluctuating airspeed indications had returned to normal.

Inspection of the No.2 engine revealed an Omega Seal disband. Based on the analysis of the engine manufacturer, the Investigation believes that the seal had sustained damage leaving a gap which allowed water ingress. The water or ice crystals entered and passed through the spinner fairing, and accreted under the annulus fillers creating an ice out-of-balance condition which led to the increase in N1 vibration, as shown in Figure 22. The use of engine anti-ice was apparently ineffective in dealing with the condition of the spinner fairing icing.

The ECAM N1 vibration advisory message disappeared after the Aircraft started to descend from FL350. The reduction in N1 vibration was due to the ice melting as the Aircraft descended into warmer air. The Investigation believes that the vibration had disappeared during the descent at the moment when the combination of the air temperature, pressure, humidity and engine rotational speed were adequate for the ice to fragment, melt, and be propelled out of the engine.

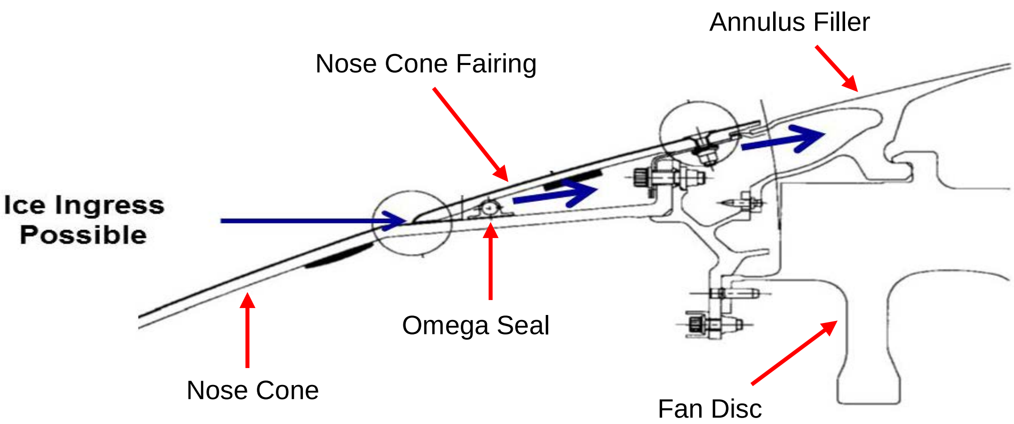

Figure 22. Ice Out-of-balance Condition Under the Annulus Fillers

The high vibration did not cause any engine damage. The engine manufacturer is working on changes to reduce the possibility of disbanding of the Omega Seal, and is considering activities to ensure that the high vibration risk is managed to an ALARP[29] level.

There was no link between the No. 2 engine N1 vibration and the unreliable airspeed indication. However, the two events occurred when the Aircraft entered an area of isolated embedded cumulonimbus clouds, which resulted in the Aircraft encountering icing conditions.

[29] The ALARP (As Low As Reasonably Practicable) principle is that the residual risk shall be as low as reasonably practicable.

2.5 Flight Crew Performance

The unreliable airspeed indication and dual ADR fault scenarios were included in the A340 First Type Rating Course, the Operator Conversion Course, and in Recurrent Training. All the flight crew members had attended the required training as per the *Operations Manual- Part D*.

The flight crew attempted to re-engage the AP by resetting the FCCs and FMGECs using the QRH COMPUTER RESET TABLE. There was no evidence that the DC BUS 2 FAULT caution was present prior to the reset. This caution is a pre-requisite to reset the FCCs. However, this action did not succeed in re-engaging the autopilot.

Thereafter, the flight crew initiated communication about the situation with the Operator's maintenance control center (MCC). The MCC suggested resetting the computers of both the System Data Acquisition Concentrator (SDAC) and the Flight Control Data Concentrator (FCDC). This was attempted by the crew but was unsuccessful in achieving re-engagement of the AP. The MCC also provided advice on the N1 vibration on the No. 2 engine.

The flight crew were not aware that the AP cannot be re-engaged when the FCPCs have rejected the three ADRs, since the Operator’s *abnormal and emergency procedures* for NAV ADR DISAGREE did not contain information related to that condition. This led the crew to attempt re-engaging the AP by resetting the FCCs and FMGECs, and then by resetting the SDAC and FCDC, without success.

As stated in the *QRH*: "In all other circumstances, where a failure is suspected or detected, there is no specific recommendation as to whether a reset should be performed or not, except those where a reset is specifically forbidden.” Therefore, the reset of the FMGECs, FCCs and both SDAC and FCDC was allowed. The results of the resets revealed no issues related to computer malfunction.

Due to the unsuccessful attempts to re-engage the AP, the No. 2 engine N1 vibration, the uncertainty of the flight crew as to the weather radar serviceability, and the weather conditions, the captain decided to divert to Singapore, in coordination with the MCC. The NOC was informed of the diversion decision by the flight crew.

The diversion decision was based on the above conditions, and the loss of capability of the Aircraft to operate to RVSM requirements.

The captain informed Melbourne ATC about the loss of RVSM capability via CPDLC and of his decision to divert to Singapore.

According to *CAR Part IV - CAR-OPS 1.872*, an automatic altitude control system is required for operation in defined RVSM airspace. Although, there is no explicit requirement that the system must be operational, the Investigation considers that the interpretation of the provision is that the system shall be operational. Since the AP could not be re-engaged, the Aircraft had lost the main requirement to continue flying in RVSM airspace.

The Investigation believes that the flight crew had complied with the *CAR* requirements and practiced efficient CRM when they decided to vacate RVSM airspace by descending the Aircraft to FL290.

2.6 Design Requirement of the Pitot Probe

There are no restrictions in the *Flight Crew Operating Manual (FCOM)* related to operating the Aircraft in severe icing conditions. The environmental conditions that can cause icing, especially at high altitudes, have the potential to adversely affect the redundancy of the three independent airspeed sensing systems.

The design of the pitot probes has been demonstrated to be vulnerable to ice obstruction in specific conditions. In this Incident, the condition was beyond the *JAR* specification and the manufacturer's requirements. However, the trend of unreliable airspeed events reduced when the Goodrich model 0851HL pitot probes started to replace the older probes approved for the Airbus A330/A340 aircraft.

The BEA had addressed safety recommendations to the European Aviation Safety Agency (EASA) in the Final Investigation Report of the AF447 accident investigation related to the ice protection certification criteria. EASA has taken into account those recommendations. In particular, new environmental icing conditions were recently published in CS25/Amendment 16 and CS-E/Amendment 4.

3. Conclusions

3.1 General

From the evidence available, the following findings, causes and contributing factors were determined with respect to this Incident. These shall not be read as apportioning blame or liability to any particular organisation or individual.

To serve the objective of this Investigation, the following sections are included in the conclusions heading:

- **Findings-** are statements of all significant conditions, events or circumstances in this Serious Incident. The findings are significant steps in this Serious Incident sequence but they are not always causal or indicate deficiencies.
- **Causes-** are actions, omissions, events, conditions, or a combination thereof, which led to this Serious Incident.
- **Contributing factors-** are actions, omissions, events, conditions, or a combination thereof, which, directly contributed to this Serious Incident and if eliminated, avoided or absent, would have reduced the probability of this Serious Incident occurring, or mitigated the severity of the consequences of the Serious Incident. The identification of contributing factors does not imply the assignment of fault or the determination of administrative, civil or criminal liability.

3.2 Findings

3.2.1 Findings Relevant to the Aircraft

(a) The Aircraft was certified, equipped, and maintained in accordance with the existing requirements of the General Civil Aviation Authority, United Arab Emirates.

(b) The Aircraft was airworthy when dispatched for the flight.

(c) Examination of the Aircraft maintenance records did not reveal any evidence of pre-existing Aircraft systems anomalies that could have contributed to the Incident.

(d) The pitot probes on the left side of the Aircraft, most probably, were being intermittently obstructed by ice crystals.

(e) Three occasions of unreliable airspeed indication on CAS1 and CAS3 were experienced, which resulted in reversion of the flight control law to Alternate Law, and prevented the re-engagement of the autopilot during the remainder of the flight.

(f) The logics of the FMGES and FCS related to unreliable indicated airspeed functioned correctly as designed.

(g) No deficiencies in the systems functionality related to airspeed, altitude, AOA, or temperature were found.

(h) The ambient temperature and the Aircraft altitude were beyond the icing envelope of the *JAR* specification and the manufacturer requirements.

(i) On the No. 2 engine, outer surface the Omega Seal was in disband condition, which made the omega seal loose on the Nose Cone and allowed water ingress.

(j) Water or ice crystals entered and passed through the spinner fairing and accreted under the annulus fillers creating an ice out-of-balance situation, which led to the increase of N1 vibration beyond the maximum over a period of 1 hour and 20 minutes.

(k) The N1 vibrations of No. 2 engine disappeared during the descent, when the combination of air temperature, pressure, humidity and engine rotational speed were adequate for the ice to melt, fragment and be propelled out of the engine.

(l) The Aircraft lost the capability to operate in RVSM airspace.

(m) There was no link between the unreliable airspeed indication and the No. 2 engine N1 high vibration events.

3.2.2 Finding Relevant to the Crew

- The flight crew were licensed and qualified to operate the flight in accordance with the existing requirements of the General Civil Aviation Authority, United Arab Emirates.

3.2.3 Findings Relevant to the Flight Operation

(a) Flight crew training for operations with unreliable airspeed indication and dual ADR faults were included in the A340 First Type rating Course, Operator Conversion Course, and in Recurrent Training. The flight crew had attended the required A340 training, which included the unreliable airspeed indication and dual ADR fault training as per the *Operations Manual, Part D*.

(b) The weather radar functioned correctly; however, it is most probable that an incorrect radar tilt setting was selected such that the flight crew was not made aware that the Aircraft would encounter an area of isolated embedded cumulonimbus clouds.

(c) The abnormal and emergency procedures for NAV ADR DISAGREE given in the *FCOM* did not reflect the fact that the autopilot cannot be re-engaged if the FCPCs have definitively rejected the three ADRs, nor did the *FCOM* state that the automatic landing capability degrades to CAT1.

(d) The crew followed the necessary procedure to vacate RVSM airspace by descending to FL290, following the unsuccessful attempts to re-engage the AP.

(e) The crew maintained visual meteorological conditions (VMC) during the diversion, since they were unable to ascertain the serviceability of the weather radar until the approach to Singapore.

(f) CRM was practiced appropriately during the Incident, before and during the descent and the approach to the diversion airport.

(g) The Aircraft landed uneventfully at Singapore International Airport.

3.2.4 Finding Relevant to Weather

- The Incident occurred when the Aircraft entered an area of isolated embedded cumulonimbus clouds, which resulted in the Aircraft encountering icing conditions.

3.2.5 Finding Relevant to Specification and Certification

- The Aircraft experienced icing conditions in which the altitude and static ambient temperature (SAT) conditions were outside the *JAR* specification and the Aircraft Manufacturer requirements.

3.3 Causes

The Air Accident Investigation Sector determines that:

3.3.1 The cause of the Unreliable Airspeed Indication Serious Incident was the intermittent obstruction of the Aircraft left side pitot probes due to, most probably, accumulations of ice crystals.

3.3.2 The cause of the No. 2 engine N1 high vibration was the ingress of water through a gap created after the Omega Seal disbanded. The water froze to ice, which entered and passed through the spinner fairing and accreted under the annulus fillers.

3.4 Contributing Factors to the Incident

The Investigation identifies the following contributing factors to this Unreliable Airspeed Indication Serious Incident:

3.4.1 An incorrect weather radar tilt setting was selected. Accordingly, there was no predictive detection of the cumulonimbus cloud that may have enabled the crew to take avoidance maneuvers.

3.4.2 The ambient temperature and the Aircraft altitude were outside the icing envelope parameters of the *JAR* specification and the manufacturer's design requirements for pitot probes.

4. Safety Recommendations

4.1 General

The safety recommendations listed in this Report are proposed according to paragraph 6.8 of *Annex 13 to the Convention on International Civil Aviation*[30], and are based on the conclusions listed in heading 3 of this Report; the GCAA expects that all safety issues identified by the Investigation are addressed by the nominated States and organizations.

4.2 Safety Actions Taken and in Progress

Safety actions were taken following the occurrence of the Incident. Some of the safety actions were taken following the AF447 accident, and these safety actions are also applicable to this Incident.

4.2.1 Bureau d'Enquêtes et d'Analyses (BEA)

The report of the investigation into the AF447 accident contains safety recommendations, formulated by the BEA and addressed to EASA, related to the design certification criteria for the pitot probe.

The BEA recommended that EASA undertake studies to determine with appropriate precision, the composition of cloud masses at high altitude; and in coordination with the other regulatory authorities, based on the results obtained, to modify the pitot probe design certification criteria.

4.2.2 The European Aviation Safety Agency (EASA)

EASA has taken the referenced BEA recommendations into account, and the required actions are in progress (see paragraph 1.18.5).

A new pitot probe certification specification for environmental icing conditions specifically related to ice crystals and mixed phase was introduced by CS-25/Amendment 16 and CS-E/Amendment 4 on 12 March 2015.

Currently, EASA is working with Airbus on the certification of new pitot probes for Airbus aircraft. EASA received the certification application at the end of 2014, it is expected that the certification project durations will be approximately one year.

The new probes will be compliant with a Special Condition mandating environmental conditions equivalent to the qualification aspects in icing conditions to the new requirements of CS-25 Amendment 16.

Discussions between EASA and the Aircraft Manufacturer related to forward fit and retrofit policy has not yet taken place.

The AAIS will not repeat similar recommendations to those contained in the BEA AF447 investigation report.

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[30] Paragraph 6.8 of *Annex 13 to the Convention on International Civil Aviation* states: 'At any stage of the investigation of an accident or incident, the accident or incident investigation authority of the State conducting the investigation shall recommend in a dated transmittal correspondence to the appropriate authorities, including those in other States, any preventive action that it considers necessary to be taken promptly to enhance aviation safety'.

4.2.3 Airbus

The manufacturer has published the following documents:

- *Flight Operations Briefing Notes – Adverse Weather Operations/Optimum Use of the Weather Radar;*
- *Getting to Grips with Cold Weather Operations*'; and
- *Flight Crew Training Manual, revision dated 13 MAR 15.*

These documents were published to increase pilot awareness of adverse weather hazards and to describe the techniques for optimum use of weather radar.

The relevant abnormal and emergency procedures have been updated by the Aircraft manufacturer, by adding a note highlighting the loss of the autopilot when NAV ADR DISAGREE is detected by the FCPCs, and referencing the relevant inoperative systems. The revision was provided to the Operator on 27 November 2013.

Airbus has already launched the design of new pitot probes with the probe manufacturers. The new pitot probes will comply with the new regulation and will be available for production as soon as they are certified.

4.2.4 Rolls Royce

The engine manufacturer is working on solutions to reduce the possibility of Omega Seal disband, and is considering other possible changes to ensure that the high vibration risk is managed.

Therefore, the AAIS will not issue a similar recommendation.

4.3 Safety Recommendations

The Air Accident Investigation Sector recommends that:

4.3.1 The Operator should:

SR 41/2015

Add to the existing initial and refresher type training syllabi, appropriate material such as that contained in the published manufacturer documentation, regarding optimum techniques for use of the manual weather radar, in order to maximize the weather surveying and detection capabilities.

4.3.2 The European Aviation Safety Agency (EASA) should:

SR 42/2015

Consider mandating the qualification aspects of the pitot probes in icing conditions to meet the new requirements of *CS-25*, Amendment 16, for forward fitting to aircraft in production and for retrofitting to aircraft already in service.

4.3.3 The General Civil Aviation Authority of the United Arab Emirates should:

SR 43/2015

Establish communication with the type certification authorities, recognized by the UAE, to examine the 'ice protection certification specification' regarding aircraft operating outside the older applicable certification specification, *JAR part 25*, and the new EASA *CS-25*, Amendment 16.

SR 44/2015

Take the necessary action to require operators which are regulated by the General Civil Aviation Authority of the United Arab Emirates to include optimum techniques for use of manual weather radars in initial and refresher type training syllabi.

Appendix 1. Post Flight Report

Post Flight Report (PFR) presents all ECAM warning/caution and failure messages recorded during the Incident flight.

System	Cockpit Effect	Meaning	Remarks
FCS	NAV FM/GPS POS DISAGREE	When the FMS 1 or 2 position differs from the GPS 1 or 2 position by more than: - 0.5 minutes of latitude or: - 0.5 minutes of longitude, if the aircraft latitude is included between 0 ° and 45 °. - 0.7 minutes of longitude, if the aircraft latitude is included between 45 ° and 60 °. - 1 minute of longitude, if the aircraft latitude is included between 60 ° and 70 °. Above 70 ° of latitude, a longitude difference does not trigger the alarm.	Time: 0050 Aural Warning : single chime; Master Light: Master Caution
FCS	NAV IAS DISCREPANCY	Caution activated when there is a discrepancy between the speeds displayed on the PFDs	Time: 0051; FDR Time: 00:50:05 Aural Warning : single chime; Master Light: Master Caution
FCS	NAV ADR DISAGREE	Disagree between two ADRs, the third one being failed or rejected by the PRIMs.	Time: 0051; FDR Time: 00:50:12 Aural Warning : single chime; Master Light: Master Caution
FMGES	FLAG ON CAPT PFD SPD LIMIT (red)	Speed limits not longer displayed on captain PFD Both FMGCs (flight envelope part) are inoperative, or in case of an SFCC dual flap/slat channel failure. In this case, the following PFD information is lost: VLS, S, F, Green Dot, Vtrend, VMAX, VFE next, VSW.	Time: 0050; FDR Time: 00:50:12
FMGES	FLAG ON CAPT	Disconnection of captain flight	Time: 0050;

	PFD FD (red)	director Both FMGECs fail, or if both FDs are disengaged and the FD pb is on and the attitude is valid.	FDR Time: 00:50:12
FMGES	FLAG ON F/O PFD SPD LIMIT (red)	Speed limits not longer displayed on first officer PFD Both FMGCs (flight envelope part) are inoperative, or in case of an SFCC dual flap/slat channel failure. In this case, the following PFD information is lost: VLS, S, F, Green Dot, Vtrend, VMAX, VFE next, VSW.	Time: 0050; FDR Time: 00:50:12
FMGES	FLAG ON F/O PFD FD (red)	Disconnection of first officer flight director Both FMGECs fail, or if both FDs are disengaged and the FD pb is on and the attitude is valid.	Time: 0050; FDR Time: 00:50:12
FMGES	AUTO FLT A/THR OFF	(Involuntary) disconnection of autothrust	Time: 0050; FDR Time: 00:50:12 Aural Warning : single chime; Master Light: Master Caution
FMGES	AUTO FLT AP OFF	(Involuntary) Disconnection (disengagement) of autopilot	Time: 0050; FDR Time: 00:50:12 Aural Warning : Continuous cavalry charge 1.5 sec minimum; Master Light: Master Warning (flashing red) ECAM: AUTO FLT AP OFF red warning CLR pb on ECAM

			Control Panel: illuminated
FMGES	AUTO FLT REAC W/S DET FAULT	Windshear detection function is inoperative.	Time: 0050 Aural Warning : single chime; Master Light: Master Caution
FCS	F/CTL ALTN LAW	Alternate Law is active	Time: 0050; FDR Time: 00:50:14 Aural Warning : single chime; Master Light: Master Caution
Power Plant	ADVISORY ENG2 N1 VIBRATION	N1 Vibration of Engine 2 > 2.8 units (3.6 units in flight with ENG ANTI ICE ON)	Time: 0053
FCS	F/CTL PRIM 2 FAULT	Failure of flight control primary computer 2	Time: 0109 Aural Warning : single chime; Master Light: Master Caution
FCS	F/CTL PRIM 1 FAULT	Failure of flight control primary computer 1	Time: 0109 Aural Warning : single chime; Master Light: Master Caution
FCS	F/CTL PRIM 3 FAULT	Failure of flight control primary computer 3	Time: 0109 Aural Warning : single chime; Master Light: Master Caution
FCS	F/CTL SEC 1 FAULT	Failure of flight control secondary computer 1	Time: 0109 Aural Warning : single chime; Master Light: Master Caution
FCS	F/CTL SEC 2 FAULT	Failure of flight control secondary computer 2	Time: 0109 Aural Warning : single chime; Master Light: Master Caution
FMGES	FLAG ON CAPT	Map is not available on Capt ND.	Time: 0109

	ND MAP NOT AVAIL	Reasons: • The MODE CHANGE or RANGE CHANGE message has been displayed more than 6 s • A disagreement between DMC and FMGEC has been detected while EFIS control panel is failed (default mode ROSE NAV 80 nm) • The FMGEC is not able to indicate the flight plan reference point (back up mode) while PLAN mode is selected • The FMGEC has failed • The FMGEC has delivered an invalid aircraft position.	Message in Red on ND
FMGES	AUTO FLT FM 1 FAULT	Failure of Flight Management 1 (failure of FMGEC1)	Time: 0118 Local Warning: MAP NOT AVAIL on ND1 (Navigation Display on EFIS 1)
FMGES	FLAG ON F/O ND MAP NOT AVAIL	Map is not available on F/O ND. Reasons: • The MODE CHANGE or RANGE CHANGE message has been displayed more than 6 s • A disagreement between DMC and FMGEC has been detected while EFIS control panel is failed (default mode ROSE NAV 80 nm) • The FMGEC is not able to indicate the flight plan reference point (back up mode) while PLAN mode is selected • The FMGEC has failed • The FMGEC has delivered an invalid aircraft position.	Time: 0118 Message in Red on ND
FMGES	AUTO FLT FM 2 FAULT	Failure of Flight Management 2 (failure of FMGEC2)	Time: 0136 Local Warning: MAP NOT AVAIL on ND2 (Navigation Display on EFIS 2)

			When both FM1 and 2 FAULT, triggered: Aural Warning: single chime Master Light: Master Caution
FWC	F/CTL FCDC 1 FAULT	Failure of FCDC1	Time: 0135 Aural Warning: single chime Master Light: Master Caution SD page Called: F/CTL
FWC	F/CTL FCDC 2 FAULT	Failure of FCDC2	Time: 0135 Aural Warning: single chime Master Light: Master Caution SD page Called: F/CTL
FWC	FWS SDAC 1 FAULT	Failure of Flight Warning System SDAC1	Time: 0144 No warning
FWC	FWS SDAC 2 FAULT	Failure of Flight Warning System SDAC2	Time: 0144 Aural Warning: single chime Master Light: Master Caution

Appendix 2. Detailed FDR and DAR Read-out Data – Unreliable Airspeed

The FDR parameters, DAR data and PFR showed that:

- The initial conditions before the Incident were:
  - Gross Weight = 301.8 Tons
  - CG = 35.8%
  - Autopilot (AP) engaged in ALT CRZ[31] / NAV[32] Mode
  - FD1 and FD2 engaged
  - Autothrust (A/THR) engaged and managed in MACH Mode[33]
  - Flight Control in NORMAL Law
  - Slats / Flats Configuration: CLEAN (00/00)
  - TAT1 = -12^0 C
  - SAT = -42^0 C
  - Wind speed and direction: about 9 knots and 235 degrees

- Between 00:50:04 and 00:50:09,
  - Selected Mach was 0.81 Mach.
  - CAS1 (CAS of ADR1) decreased from 283 to 77 kts in about two seconds.
  - CAS2 (CAS of ADR2) remained stable at about 281 kts.
  - CAS3[34] remained stable at about 280 knots.
  - Alt1 indication started at 35,000 ft and reduced to 34,776 ft.
  - Event Description

    CAS1 being out of tolerance, the ADR1 was rejected by the FMGEC, as a result of the following:

    - FMGEC – ADR Monitoring: reducing of CAS1 was higher than 20 kts in 450msec.

[31] ALT CRZ Mode (Altitude hold of the cruise flight level) is a selected mode used to maintain a level flight at the FCU selected altitude.

[32] NAV Mode is a managed mode that steers the aircraft laterally along the flight plan defined in the FMGES.

[33] The Autothrust soft mode engages when the aircraft is in ALT CRZ mode with the autopilot engaged, autothrust engaged in MACH mode, and is within a ± 3 kt range of the target speed.

[34] CAS 3 (CAS of ADR 3) and ISIS_CAS use pressures from the same Pitot 3 and Static 3, consequently, ISIS_CAS information gives also a good indication of CAS 3 information

CAS1 being other than "Normal Operation", the ADR1 was rejected by the FCPC.

Two CAS (CAS2 & CAS3) out of 3 were still valid and consistent, which resulted in:

- autopilot1 and autothrust did not disengage;
- both FD remained engaged;
- flight controls were still in Normal laws;

- At 00:50:10, CAS 1 increased to 270 kts, All three ADRs were now valid again based on the monitoring of the ADR speeds comparison by the FCPC, and also by the FMGEC.

- Between 00:50:11 and 00:50:15
  - CAS1 decreased from 270 to 76 kts.
  - CAS2 remained constant at approximately 283 kts.
  - CAS3 decreased from 280 to 142 kts.
  - Both flight directors disengaged
  - Autopilot1 disengaged
  - Autothrust disengaged
  - Flight control law reverted from Normal to Alternate.
  - Event Description

CAS1 and CAS3 were out of tolerance and all three CAS were different, which caused the rejection of all three ADRs by the FMGEC and the FCPC.

All three ADRs were rejected as a result from the following monitoring:

- FMGEC – ADR Monitoring: at 00:50:12, the CAS3 reduced from 270 to 220 kts, which exceeded 20 kts in 450msec. ADR1 rejection was still latched by FMGEC. Consequently, all three ADRs were rejected by the FMGEC.
- Monitoring ADR Speeds Comparison by FCPC:
  - About 00:50:12, CAS1 and CAS3 decreased for more than 30 kts in 1 second, while CAS2 was stable. Consequently, the icing monitoring triggered and the Flight Control reverted to Alternate Law.

Based on the FMGEC-ADR monitoring (auto flight disconnection logic), the rejection of all three ADRs at time 00:50:12, resulted in:

- Disconnection of the auto flight system:
  - disconnection of both flight directors (FD1 and FD2);
  - the triggering of captain and first officer master warning;

- disconnection of autopilot1, which triggered the message "AUTO FLT AP OFF" on the ECAM (shown on PFR at time 00:50);
- loss of autothrust, which triggered the message "AUTO FLT A/THR OFF" (shown on the PFR at time 00:50).

Based on the FCPC-ADR monitoring (flight control monitoring), the rejection of all three ADRs, resulted in:

➢ Flight control law transition from Normal to Alternate Law at 00:50:14, and triggering the message "F/CTL ALTN LAW" on the ECAM (shown on PFR at time 00:50).

- Between 00:50:16 and 00:50:18, CAS1 increased from 76 to 285 kts and maintained this value. CAS3 was still out of tolerance.
  - o Event Description

    ADR1 and ADR2 were used again by the FMGEC since CAS1 was back in tolerance and CAS2 remained in tolerance. The autopilot was still off disengaged.

    Since two CAS (CAS1 and CAS2) were again valid and consistent together, consequently:

    ➢ both FDs re-engaged automatically at 00:50:18.

    ADR1 and ADR2 were valid again through the ADR speeds comparison monitoring.

- At 00:50:19, Wing anti-ice was selected.

- At 00:50:22, CAS1 and CAS2 were about 279 and 278 kts, respectively. CAS3 increased to 272 kts. Subsequently, Normal Law was activated.
  - o Event Description
    The three CAS were again valid related to the FMGEC and FCPC.
    After 10 seconds of triggering the icing monitoring, and when the three CAS were again valid, the 3 ADRs were used again by the FCPC, consequently:

    ➢ Flight control law activation returned back to Normal Law.

- Between 00:50:45 and 00:50:55,
  - o Thrust Lever Angle changed from Maximum detent point to about 33°.

- At 00:50:56,
  - o Thrust Lever Angle changed from 33.0° to 28.0° (between Max climb detent point and Idle Stop)

- At 00:51:02, autothrust was re-engaged:
  - o Mach target was selected to 0.65.
  - o EPR decreased from 0.90 to 0.75 as commanded.

  - The 3 CAS were consistent at approximately 288 kts.

- Between 00:51:04 and 00:51:07,
  - CAS1 decreased from 286 to 206 kts in 2 seconds, then, increased again to 284 kts in 1 second.
  - CAS2 and CAS3 remained stable at about 287 kts.
  - Both FDs remained engaged.
  - Event Description
    CAS1 was out of tolerance for about one second and returned to normal. Consequently, ADR1 was rejected by the FMGEC temporarily for about one second.
    Both FDs remained engaged as two CAS (CAS2 and CAS3) out of the three remained stable during the temporary ADR1 rejection.

- Between 00:51:11 and 00:51:22,
  - CAS1 decreased from 286 to 70 kts.
  - CAS2 and CAS3 remained stable and close together.
  - At 00:51:16, speed target was selected from 222 to 280 kts.
  - TRA increased from 28.0° to 35.6°, consequently:
    - EPR increased from 0.75 to 1.06.
  - Event Description

    During the time-interval, CAS1 reduced and became out of tolerance.

    At 00:51:13 based on the FMGEC-ADR monitoring, ADR1 was rejected by the FMGEC when CAS1 reduced from 262 to 122 kts in one second, which can be considered that the reduction was more than 20 kts in 450 milliseconds.

    CAS1 was more than 16 kts different to the other two CAS (CAS2 and CAS3) for more than 10 seconds at 00:51:22. Based on the monitoring ADR speeds comparison by the FCPC, this resulted in rejection of the ADR1 by FCPC and the rejection was latched.

- Between 00:51:23 and 00:51:30,
  - At 00:51:23, CAS1 increased from 70kt to 270kt in 1 second and remained stable until 00:51:28.
  - CAS2 remained stable.
  - CAS3 decreased from 271kt to 246 kts in 1 second, decayed further to 184 kts in 3 seconds, and then increased again to 219 kts at 00:51:30.
  - Flight control law reverted from Normal to Alternate at 00:51:28, and remained until the end of the flight.
  - FD1/2 and A/THR disengaged at 00:51:30.

  - Message NAV ADR DISAGREE triggered.
  - Event Description
    - FMGEC – ADR Monitoring:

      Since the AP was already disengaged, ADR1 was accepted and used again by the FMGEC after the CAS1 increased at 00:51:23 from 70 to 270 kts, and thereafter remained inside the tolerance value. CAS3 decreased, and between 00:51:24 and 00:51:25, it decreased from 219 to 189 kts (about 30 kts) in one second. Since the sampling rate for the airspeed was one data per second (1 Hz), it is most likely that the decrement of CAS3 was more than 20 kts in 450 msec , which caused the FMGEC to reject ADR3.

      At 00:51:30, CAS1 reduced from 252 to 110 kts in one second, which was more than 20 kts in 450 msec. Consequently, the remaining ADRs (ADR1 and 2) were also rejected by the FMGEC, and this resulted in disengagement of the autothrust and both flight directors.

    - FCPC – ADR Monitoring:

      ADR1 was already rejected by the FCPC before 00:51:23, while ADR2 and ADR3 were still valid. However, CAS3 was continuously reducing and consequently at 00:51:28, due to the CAS2 and CAS3 discrepancy, the FCPC rejected the remaining ADR2 and ADR3, through monitoring ADR speeds comparison. Consequently, all three ADRs were rejected by the FCPC.

      Flight control reverted to Alternate law. Those rejections were latched until the end of the flight, also the reversion to Alternate Law remained. NAV ADR DISAGREE message was triggered as result of all ADR being rejected.

- Between 00:51:31 and 00:51:32,
  - At 00:51:31, CAS1 increased from 110kts to 263kts and maintained for two seconds only.
  - CAS2 remained stable.
  - CAS3 was out of tolerance.
  - FD1 and FD2 were re-engaged at 00:51:32.
  - Event Description

    The increase of CAS1 was back into the tolerance value, and CAS2 remained at the correct indication, consequently, both ADR1 and ADR2 were again valid and were used by the FMGEC. Consequently, the FD1 and FD2 were automatically re-engaged.

- Between 00:51:33 and 00:51:46,
  - CAS1 decreased from 263kts to 71kts and maintained out of tolerance during this mentioned time-interval.

- CAS2 remained stable.
- CAS3 was out of tolerance.
- FD1 and FD2 were disengaged.
- Event Description

  The CAS discrepancy between the two remaining ADR1 and ADR2 were rejected through monitoring, which led to the rejection of all three ADRs by the FMGEC. The rejection of all three ADRs led to the disengagement of both FDs.

- From 00:51:47 and after
  - At 00:51:47, CAS1 increased from 84 to 252 kts, and CAS3 from 101 to 256 kts.
  - Both flight directors were re-engaged at 00:51:49.
  - AT was re-engaged at 00:51:54
  - Event Description
    CAS1 and CAS3 were back to the in tolerance value and consistent compared to CAS2, which led to the acceptance of all 3 ADRs by both FMGECs (1 & 2). Subsequently, the flight directors were automatically re-engaged, and the autothrust was able for re-engagement as performed by the flight crew.

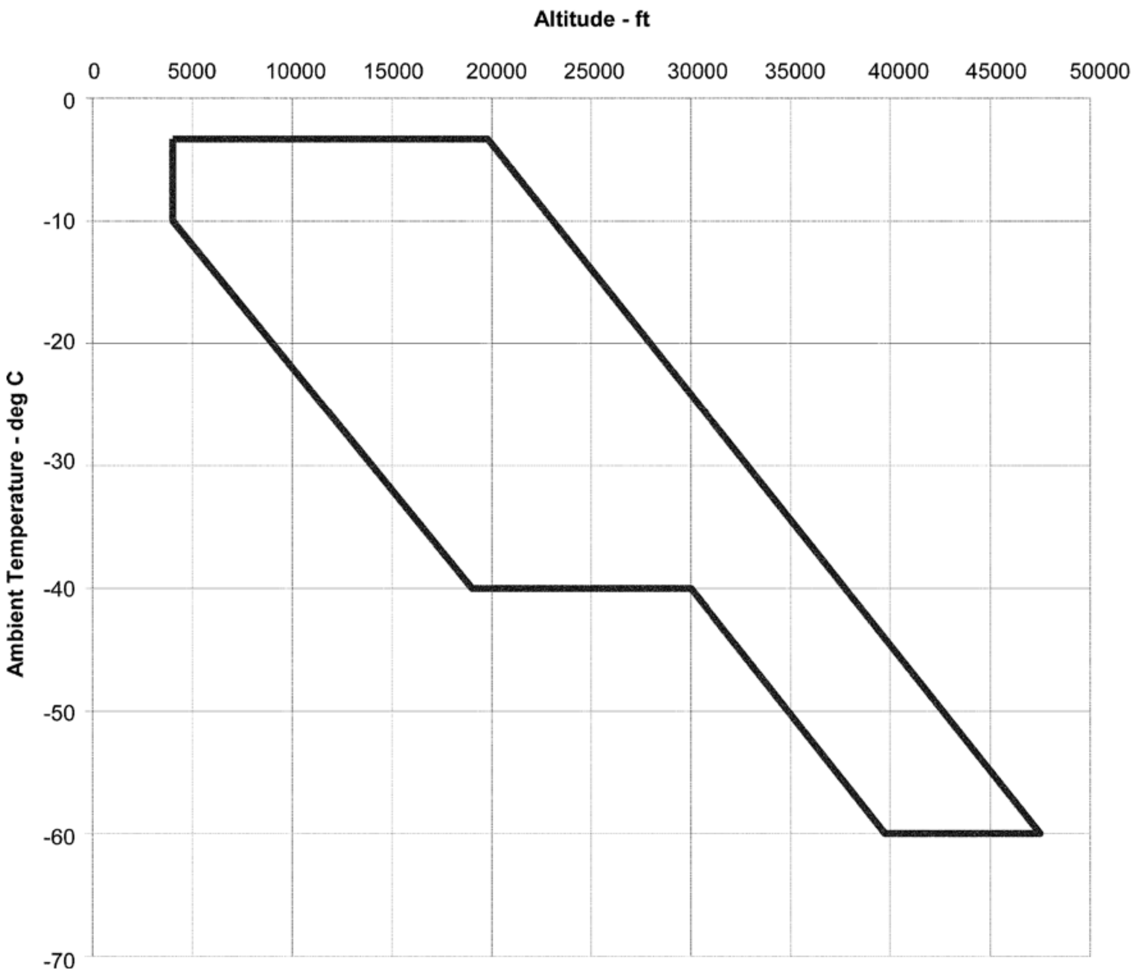
Appendix 3. Deep Convective Clouds (Appendix P of CS-25 / Amendment 16)

The mixed phase and ice crystal envelope according to Appendix P of CS-25 Amendment 16 is as follows:

“**Appendix P - Mixed phase and ice crystal icing envelope (Deep convective clouds)**

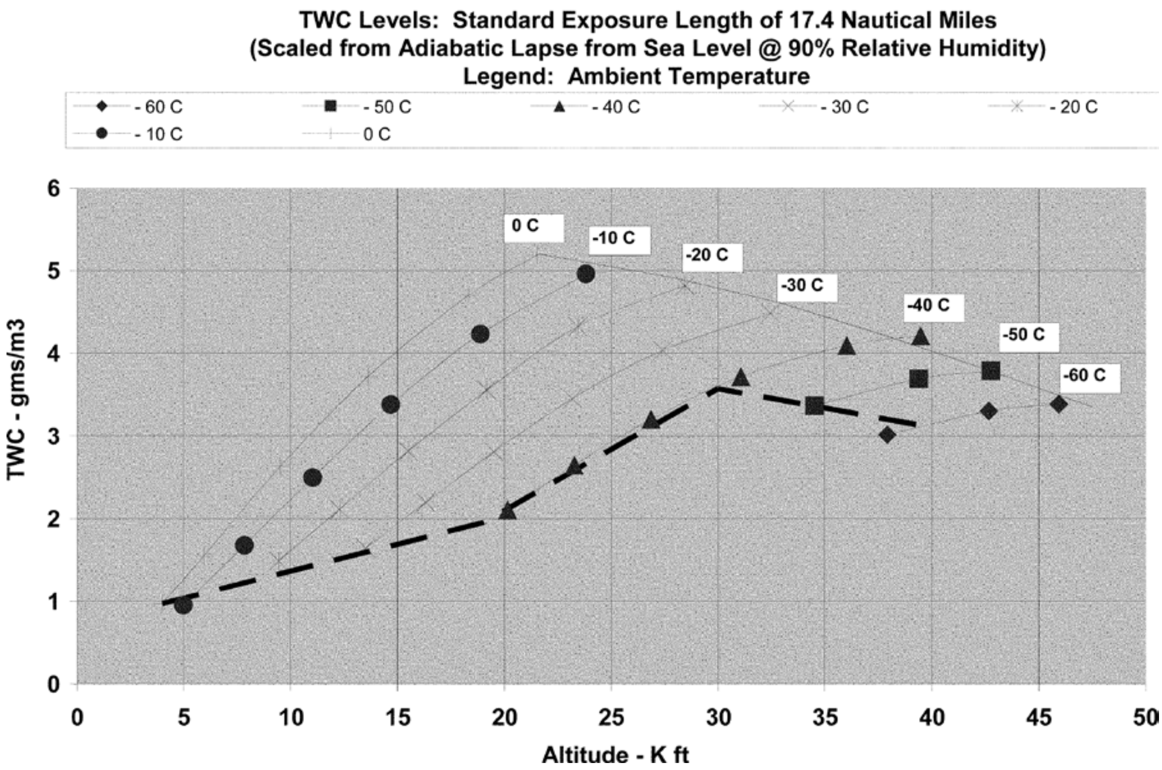
The ice crystal icing envelope is depicted in Figure 1 below.

Figure 1 - Convective Convective Cloud Ice Crystal Envelope



Within the envelope, total water content (TWC) in g/m^3 has been determined based upon the adiabatic lapse defined by the convective rise of 90 % relative humidity air from sea level to higher altitudes and scaled by a factor of 0.65 to a standard cloud length of 32.2 km (17.4 nautical miles). Figure 2 displays TWC for this distance over a range of ambient temperature within the boundaries of the ice crystal envelope specified in the figure 1.

Figure 2 – Total Water Content



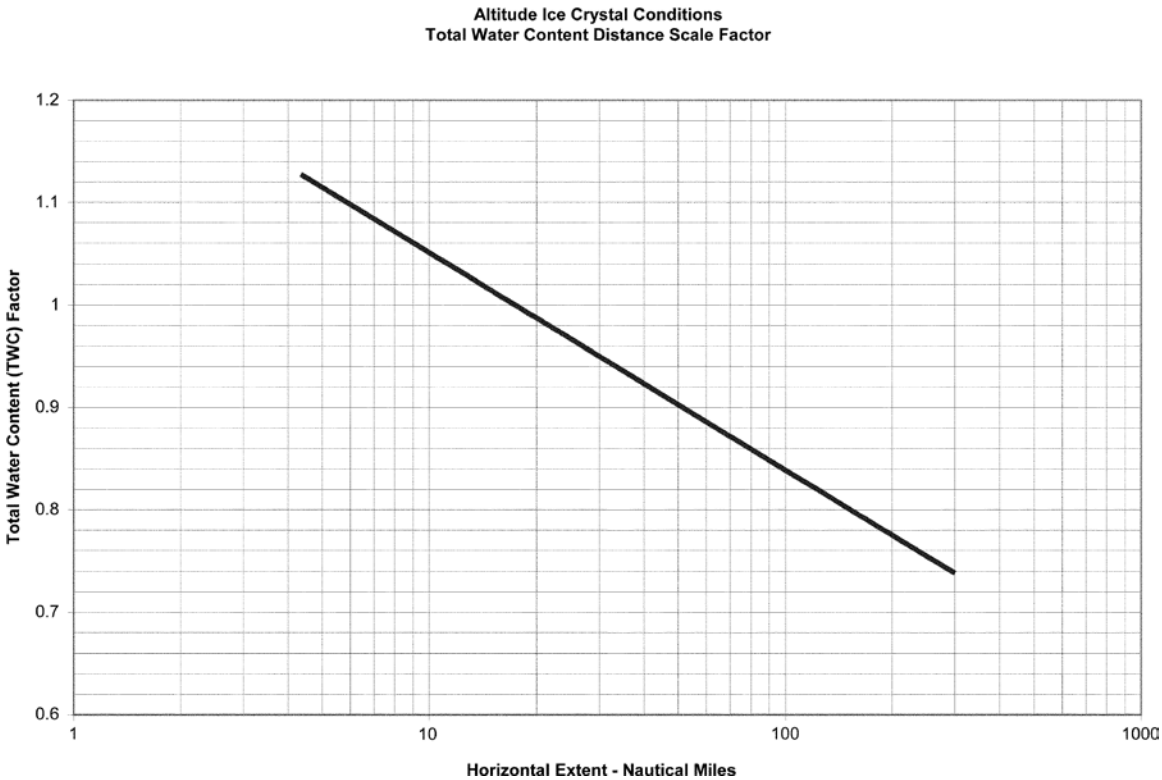
Ice crystal size median mass dimension (MMD) range is 50–200 microns (equivalent spherical size) based upon measurements near convective storm cores. The TWC can be treated as completely glaciated (ice crystal) except as noted in the Table below.

Table 1 – Supercooled Liquid Portion of TWC

Temperature range – deg C	Horizontal cloud length	LWC – g/m^3
0 to -20	≤92.6 km (50 nautical miles)	≤1.0
0 to -20	Indefinit	≤0.5
< -20		0

The TWC levels displayed in Figure 2 represent TWC values for a standard exposure distance (horizontal cloud length) of 32.2 km (17.4 nautical miles) that must be adjusted with length of icing exposure.

Figure 3 – Exposure Length Influence on TWC



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